A CENTURY OF PROGRESS SERIES

MAN AND MICROBES

BY

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TO NAN

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PREFACE

THE celebration of a Century of Progress almost coincides with the three hundredth anniversary of the birth of van Leeuwenhoek, the discoverer of microbes. In the latter part of the 17th. century, after about 1680, Leeuwenhoek saw and pictured bacteria and other germs. But the science of microbiology is by no means as old as is indicated by these dates. It is in reality one of the youngest members of the group of biological sciences. Intensive study of the nature and activities of microbes is less than a hundred years old. The period since 1833, therefore, covers almost the whole of the development of the scientific knowledge of microbes.

In this small book, I have tried to give the microbes their due, indicating their useful and essential activities as well as their devastating effects. The occasional spectacular havoc wrought by the germs of disease should not divert attention from the invaluable chemical services which hosts of microbes are quietly rendering man, animals and plants all the time.

It is obvious that in attempting to picture such a broad field on a few pages I have had to make a

miniature of the whole by taking small representative samples from some parts of it. Many details had to be left out. Some details have been left out intentionally, while others, no doubt, have been omitted through ignorance.

Anyone familiar with microbiology will recognize the sources of my information. Those sources are too numerous to acknowledge in detail here. I am especially indebted to Professor Ralph P. Tittsler, who read the manuscript and gave me valuable suggestions.

STANHOPE BAYNE-JONES.

CHAPTER I

MICROBES

When it came to the recognition of microbes, seeing had to go before believing. Varro, an ancient Roman poet, had talked about invisible germs. Fracastorius, a few years after the discovery of America, wrote shrewd books about the seeds of disease. While these fancies could allure the explorer and serve for the making of big books, they could not convince anyone because they were at best as unproved as the guesses about the mythical Atlantis. Apparatus and the experimental method were needed to show that microbes existed and to test the notions about what they could do.

In the first place, magnifying glasses had to be improved enough to give a close-up of the infinitely small. The first man who made a microscope to do this was an extraordinarily industrious, versatile and sharpsighted amateur scientist named Anthony van Leeuwenhoek, who lived at Delft in Holland about two hundred and fifty years ago. He made little lenses, with frames to hold them in focus over his preparations. These magnified

about 300 times. Nowadays, we count that low magnification, but it was enough to let Leeuwenhoek look for the first time into an undiscovered world. He found that drops of well-water, scrap-

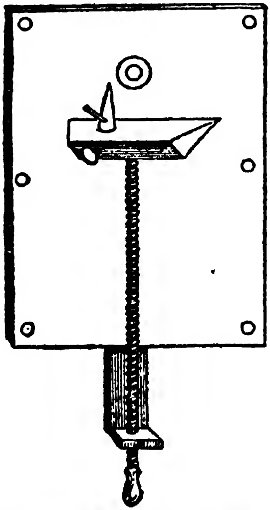

Fig. 1. One of Leeuwenhoek's microscopes. The lens was held in a small frame in the metal plates. The object to be examined was put on the pointed rod and moved into focus by means of the screw. (From "Bacteriology," by H. W. Conn and H. J. Conn, Williams and Wilkins Co., Pub., Baltimore, 1926.)

ings from teeth, beer-wort and "infusions of pepper-corns" were swarming with "little beasties." His accurate descriptions and drawings leave no doubt that he saw bacteria and other microbes.

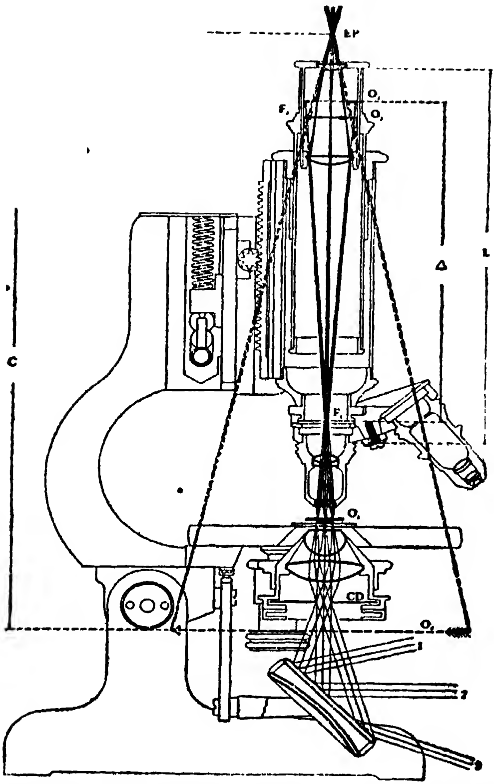

Fig. 2. Diagram of a modern compound microscope, showing the stand, systems of objectives and condenser. F_1, upper focal plane objective; F_2, lower focal plane of eyepiece; Δ, optical tube length = distance between F_1 and F_2; O_1, objective; O_2, real image in F_2, transposed by the collective lens, to O_3, real image in eyepiece diaphragm; O_4, virtual image formed at the projection distance C 250 mm from EP, eyepoint; CD, condenser diaphragm; L, mechanical tube length (160 mm); 1, 2, 3, three pencils of parallel light coming from different points of a distant illuminant, for instance, a white cloud, which illuminate three different points of the object. (Courtesy of Bausch and Lomb Optical Co., Rochester, N. Y.)

Leeuwenhoek saw a great many things that no one before him had seen. Henry Baker, writing about him in 1740 said that he was the "famous Mr. Leeuwenhoek, who, by his Glasses, made such wonderful Discoveries in the *Minutiae* of Nature, as have laid the Foundations of a Philosophy unknown to preceding Ages." He has the glory of being the founder of a great division of the science of life.

Since his day, hundreds of improvements have been made in microscopes. A picture of one of Leeuwenhoek's microscopes beside a modern microscope shows the changes made in the outward appearance of the instrument. Thanks to researches of the optical physicists and the skill of glass-makers, the greatest improvements have been made in the lenses inside the instrument and in ways of getting light on the object under examination. It is easy now to use sharply resolving magnifications up to 2500 diameters or more. Nevertheless, the microbiologist is not satisfied with even his best instrument, because he cannot yet see some still smaller things which seem to behave like microbes, living in a region beyond the reach of the microscope.

Most microbes are transparent bits of jelly-like material and are not enough more dense than water so that they can be seen well under ordinary

conditions. The next step, therefore, was to give them more contrast. A linen draper invented the microscope and the dyer of fabrics helped to make microbes more visible by showing how they could be stained. In the seventies and eighties of the last century, the microbiologist took advantage of the aniline dyes discovered by the chemist. These gorgeous colors made the bodies of the microbes stand out sharply against a colorless background. They did more than that. The dyes entered into combination with different parts of the microbes and with different kinds of microbes according to chemical and physical reactions. A procedure for increasing visibility became a method of microchemistry. The use of it has shown the shapes and structure of microbes, has told something about their composition, and has been the basis of a chemical attack upon the germs of disease.

With these good methods for seeing microbes, we should set about measuring them to get some idea of the magnitude of their size. A special unit of measurement is required. This is the micron, whose symbol is the Greek letter Mu (μ). A micron is 0.001 millimeter or approximately 1/25,000 of an inch. With ordinary light and the best lenses, it is possible to distinguish a dot or a line about one-quarter of a micron in width, approxi-

mately 1/100,000 of an inch. With special illumination and ultraviolet light, particles several hundred times as small as this can be seen. The micron would be too large a unit for anyone

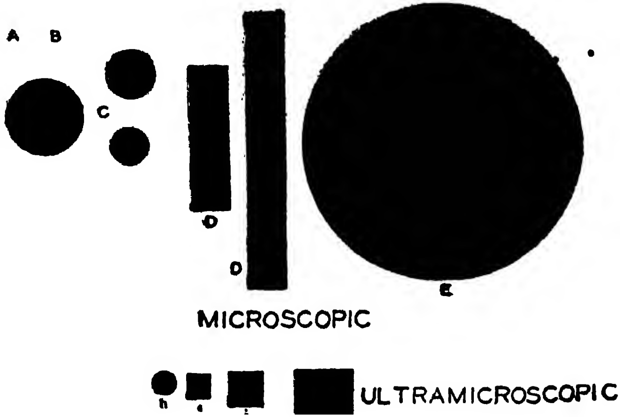

FIG. 3. Diagram to show relative sizes of microbes and other small particles. A, colloidal gold suspension particles (0.006–0.15 micron); B, settled gold suspensions, (0.075–0.2 micron); C, various types of spherical bacteria, cocci (0.5–1 micron); D, anthrax bacilli (4 x 1, 10 x 1 microns); E, human red blood corpuscle (7.5 microns); f, hydrogen molecule; g, alcohol molecule; h, molecule of soluble starch; i, j, k, smallest particles of colloidal gold visible under the ultra microscope. Magnifications: A to E, ×10,000 diameters; f to k, ×1,000,000 diameters. (From "Microbiology," by B. F. Lutman. McGraw-Hill Book Co., Inc., Pub. N. Y. 1929.)

working with atoms and molecules, but it is about right for the microbiologist. The sizes of microbes vary from several hundred microns to fractions

of a micron. There is much more diversity in size in the microbe population than in the human. Giants and pygmies are more nearly of a size than some of the giant microbes and their tiny associates. By making a scale drawing of a human blood corpuscle beside some of the bacteria, grains of starch and particles of colloidal gold, some idea of comparative sizes can be gained.

Everyone who has worked with microbes has marvelled at the smallness of their size and has tried to compare familiar objects with them. This usually leads to the ridiculous use of figures which once ended with the statement that if all the statisticians were laid end to end—it would be a very good thing indeed. One way of making the comparison is to reduce men to microbes. Suppose the 25,000 soldiers of a modern American infantry division were formed up in a single rank with an allowance of 18 inches for each man. This line would be about 7¼ miles long. Suppose, next, that some omnipotent general officer from headquarters should command "Dwindle," and that at the word of command, each soldier would shrink to the width of an average bacterium, 1 micron, and close up on his neighbor. Their line would then be about 1 inch long. Twenty-five thousand typhoid germs could lie comfortably side by side in an inch. The other way of making

the comparison is to imagine a 6 foot man, 18 inches broad, magnified 1,000 times. He would be 6,000 feet tall and 1,500 feet wide. At this magnification, some bacteria are about the size of the period at the end of this sentence and some are about as wide as one of the lines in these letters.

In general, a single microbe weighs just a little more than a drop of water of the same volume. A microbe with a volume of 1 cubic micron and a specific gravity of 1.2 would weigh 0.0000000012 milligram. This means that it would take about 833 million microbes of this size to weigh 1 milligram. As there are 1,000 milligrams in a gram and about 28.3 grams in an ounce, 28,300 times 833 million of these microbes would be needed to balance an ounce weight. Of course, the larger microbes would weigh more and fewer would be needed to balance an ounce. Even then, when we take into consideration that about 80 per cent of this material is water, it is astonishing how little solid matter there is in a microbe. The figures are inconceivable. They serve to show that a living germ is not apt to need a great bulk of food and they give us a hint that microbes must depend upon numbers to do the tremendous things they accomplish.

Microbes secure these numbers of themselves by reproductive processes that have a speed beyond

the dreams of guinea pigs. Progeny is produced relatively slowly by some and very rapidly by others, by means of a number of different manoeuvers. Some form spores or seeds like puff-balls in the woods. Some put out buds which grow and break off as new individuals. Some subdivide the substance of their bodies inside of a sort of envelope and liberate from four to thirty or more new little microbes when the capsule breaks. In some varieties there is a sort of rudimentary separation of the sexes, and these opposite elements conjugate before reproduction takes place.

The vast majority of microbes which influence man, reproduce by the simple method of splitting apart. A microbe grows to a certain size and then divides into two individuals. After a while these two divide into four, and so on. Under favorable conditions, this fissioning can happen once every half hour, chiefly among the bacteria. This enormous reproductive potency leads to some startling figures. If the process went on without interruption, a single bacterium would give rise to 2^{48}, or about 281,500,000,000,000 descendants in 24 hours. If this were kept up, standing room on the earth would be gone within a week. Someone has calculated that if favorable conditions could be maintained, the progeny of one bacterium in five days would fill as much space as all the oceans on the

earth. What a tremendous overflow there would be thirty minutes later when these bacterial oceans doubled! Fortunately, favorable conditions for reproduction at this rate cannot be maintained, and the microbial population, like any other population, becomes checked and limited by food supply, the deleterious effects of the accumulation of waste products and other influences of environment.

Microbes give substance to the poet's vision of the teeming earth. Their myriads find homes and habitations in the waters, air and soil, and in and upon all the living and dead animals and plants on the earth. But it is not a matter of indifference to a microbe where it lives. Its habitat is bound up with the conditions and foods it needs for growth and reproduction. If it needs the mulch of dead leaves in the bottom of a pond it will not thrive in the lung of a man. If it requires the temperature of a hot spring it will get along very poorly or not at all on the body of a frog.

Many groups of microbes are like hardy pioneers capable of using simple substances to build up their bodies and carry on their functions. These are the free-living saprophytes, which get on best on dead matter, tearing down the carcasses of animals and plants and decomposing all sorts of waste products. In the course of these activities,

they clean up the world and make useful compounds out of things discarded by higher forms of life or from things of simpler elemental nature. Other groups have adapted themselves to dependence upon some other living organism for food and shelter and warmth. These are the parasites who sit at the tables of higher forms of life without ever paying their way. Among these are the killers, the producers of disease. They are enormously important to animals and plants because they are at times so destructive.

In all these places and under all these different conditions, the microbes are concerned in getting hold of sources of nitrogen, carbon, phosphorus, sulphur and a few other elements which they, like all other living things, need to build up their protoplasm and maintain their bodies. How they get hold of these elements and what they do to substances from which they unlock their food supplies can best be told in later chapters. One conspicuous feature of the microbes we are considering here is that none of them contains chlorophyll, the green coloring matter in the leaves of plants. Therefore, they cannot use energy from sunlight to work chemical miracles. In fact, most microbes thrive best in the dark. This has many interesting consequences, as we shall see.

It is natural that people should have started

guessing where microbes came from as soon as microbes were seen. This sort of guessing about the origin of living things has gone on for centuries and is still a serious and unsolved problem. The answer given by the early guessers when they could not see the immediate forbears of an animal or plant was that the living thing was generated "spontaneously" out of dead matter. In former times, this doctrine of spontaneous generation had all the sanctity that the wise men of their day could give it. The learned doctors published recipes telling how to generate mice from cheese, maggots from meat and bees from bulls' horns. A fierce debate, generating nothing but words, raged for years over this question. After awhile, when ingenious men attacked the problem through the experimental method of accurate observation and controlled tests, sense was extracted from nonsense.

Although the question has never been settled as to the origin of life, an immense progress in science was made by trying to find out where microbes came from. In the seventeenth century, Redi showed that if flies were kept away by gauze covering a piece of decaying meat, no maggots would appear and another shrewd naturalist proved that fleas were not generated from blankets. A hundred years later, Spallanzani made experiments with boiled liquids which were good enough to

prove that microbes would not be generated in that sort of soup if the living germs in it were killed and a seal was used to keep out others. But it took another hundred years before these experiments were generally accepted, when they were repeated and confirmed and amplified by Pasteur and Tyndall and Schwann and the others who founded the science of bacteriology shortly after the middle of the last century.

In many clever ways, they proved that substances capable of undergoing fermentation or putrefaction would remain sweet and clear if they were first heated enough and then protected from invasion by bacteria. Air admitted to these boiled liquids through heated or bent tubes or cotton plugs never started fermentation or putrefaction. Some of the flasks of liquids prepared by Pasteur sixty years ago are still sterile. No living microbe has gotten in them and none has been generated from their fermentable and putrescible contents.

Microbes were found in the air in great numbers in dusty places. In the air at the top of Mont Blanc as well as in air filtered through cotton wool, there were usually no microbes. In the course of those investigations, Appert's practical discovery that food could be preserved in jars if the jars were placed in boiling water, heated and sealed was

a basis of much scientific experimentation. It was discovered that a very high temperature and prolonged heating was necessary to render all such liquids free from germs—and these heat-resistant forms of life were found to be the spores of certain bacteria. In some cases organisms grew even when all air was excluded. These microbes were amazing creatues that could live without air.

Different kinds of microbes were discovered which could thrive in all degrees of oxygen pressure from that of the atmosphere to that of a vacuum. Practical methods of sterilization by killing bacteria by heat, many scientific and technical procedures, and a great deal about microbes were learned from the experiments done to support one side or the other of the arguments over spontaneous generation. As far as the argument is concerned, it ended by the decision that all the microbes we see come from previously existing microbes.

But where the first microbes came from—is still an open question. The first microbes may have been the first inhabitants of the earth. Perhaps they were formed from elements on the earth or grew from vital specks of inter-planetary dust which settled on this globe. Whatever may have been their origin, they seem to have been at work here long before the advent of man.

Living matter has some sort of organization. No one knows how small a particle may be and still be alive, but it is generally accepted that one of the smallest units of organization is the cell. It

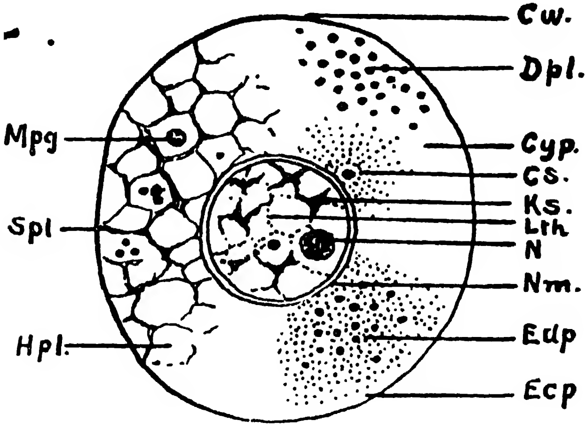

FIG. 4. Diagram of an animal cell. Cw, thin cell wall; Dpl, deuteroplasm; Cyp, cytoplasm; Cs, centrosome; Ks, karyosome; Lth, linin threads; N, nucleus; Nm, nuclear membrane; Edp, endoplasm; Cep, ectoplasm; Mpg, granules in the cytoplasm. Some unicellular microbes show all of these features. All of these structures are not recognizable in the bacteria. (From "Human Parasitology," by D. Rivas. W. B. Saunders Co., Pub. Philadelphia, 1920.)

is useful, therefore, to start with the cell in getting a notion of the make-up of microbes. Each cell consists essentially of a nucleus and its surrounding cytoplasm, enclosed in a thin membrane or a

thick rigid wall. The nucleus presides over the vital processes of the whole cell, has chief charge of reproduction and the transmission of hereditary characteristics. The rest of the jelly-like protoplasm surrounding the nucleus, the cytoplasm, is a

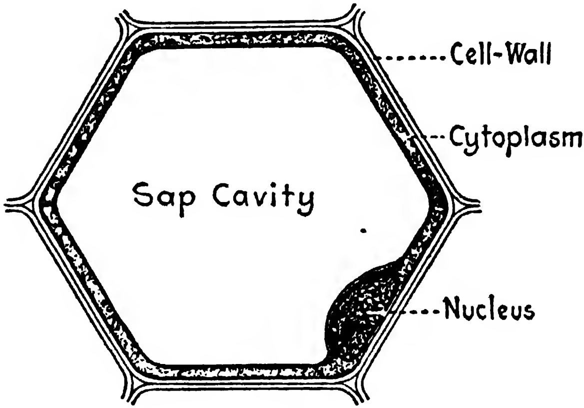

FIG. 5. A typical plant cell. Diagrammatic drawing showing the central sap-cavity, surrounded by a layer of cytoplasm which lines the thick cell wall. Embedded in the cytoplasm is the nucleus. Parts of the cell-walls of six adjacent cells are also shown. (From "Botany," by E. W. Sinnott, McGraw-Hill Book Co., Inc., Pub. N. Y., 1923.)

small factory of food-preparation, takes care of bringing things into the cell and throwing out wastes, provides the membrane or wall and sometimes special organs of locomotion. Coördinated

working of cytoplasm and nucleus are essential for the life and growth of the cell.

Among the microbes, many have all the structures of a complete cell, while others, especially the smaller germs, either lack an organized nucleus and cytoplasmic structures or have these packed into such a small space that no one can make them out. Even when all the parts of the cell cannot be seen, the microbiologist assumes that some sort of cell-structure is present. Some microbes, however, behave as if splinters of cells could grow.

It is customary to say that a microbe is a unicellular organism, even when some have several nuclei and others have no recognizable cell-structure. Some people speak of them as the "simplest" forms of life. The simplicity here is really in the mind of anyone who makes such a statement. Microbes seem simple because no one can see much of what goes on inside them. As a matter of fact, they are extremely complicated and accomplish in their "simple" little bodies most of the things that man does by such relatively clumsy apparatus as his stomach, liver, kidneys and other organs.

In order to handle these little independent cells, it has been necessary to devise a lot of technical tricks and to reproduce as nearly as possible the food supply and environmental conditions de-

manded by microbes of all degrees of fastidious tastes. With microscopes and dyes, the microbiologist tracks down the forms he is hunting and watches the behavior of the individuals he has captured. One of the primary ends to be gained is the separation of one kind of microbe out of a herd or swarm of others. With an apparatus as heavy in proportion to a microbe as a steam shovel is to a feather, a single microbe can be picked up under observation and deposited in a cage with its food.

The usual way of separating bacteria or molds from each other is by cultivation on fairly stiff jellies. Robert Koch placed bacteriology on a firm foundation when he showed how to get growth of one kind of microbe separate from others on a wabbly base of glue-like stuff made from sea weed. This agar jelly, mixed with appropriate food, is poured into a glass dish and allowed to set. Then the material containing a mixture of microbes is smeared over the surface of the jelly. After a time, a small spot appears where a single microbe settled and produced its progeny. This colony, composed of thousands of individuals, is the source of a pure culture of the microbe. A little of it, transferred by a platinum needle to a new tube of food will continue to grow and by repeated transfers the growth can be perpetuated.

Fig. 6 Colonies of bacteria growing on an agar plate. Each colony is composed of thousands of individuals. This shows the differences between the colonies of several different bacteria from dust.

Colonies of different microbes have characteris- [illegible] appearances, as shown in this picture of an agar [illegible] containing the growth of several kinds of microbes.

The kitchen where food is prepared for microbes is a most important section of the laboratory. In it, a chemically-minded chef makes up all sorts of pabula for germs, many kinds of which are much more carefully prepared than food on the tables of man. Man usually swallows a great many microbes in the food he eats. Food for microbes, however, must be rendered microbe-free without hurting its nutritive value and must be kept free from microbes until it is served to some particular germ. These foods and chemicals are used not only to keep the microbes alive and growing, but also as chemical reagents to test what microbes do.

Microbes are known by their "fruits" and waste products quite as much as by their shapes. So many of the smaller microbes look so much alike that no one can tell one from another without knowing what they do to the food they consume.

A study of the effect of microbes upon animals and plants and the effect of animals upon microbes are additional important parts of the methods of microbiology.

than plants and some are more like plants than animals, although it is not so easy to specify how all animals differ from all plants. In this population of the smallest living things there is no sharp boundary line between animals and plants. Learned papers are written to show where one or another microbe belongs. The microbes, however, unmindful of the definitions of doctors, continue in their own ways. The most minute of all are the most defiant of classification. They even puzzle the learned to determine whether they are living matter with a few of the characteristics of microbes or dead matter with some of the attributes of life. They force the microbiologist to try to find out what life really is.

It will be useful, for the sake of future reference, to put down a brief classification of the grouping of thousands of species of the microbes most important to man, as follows:

I. Microbes more like animals than plants: Protozoa:
   (a) Amoebae
   (b) Flagellates
   (c) Sporozoa
   (d) Ciliates

II. Microbes more like plants than animals: various kinds of Mycetes:
   (a) Molds, yeasts, streptothrix
   (b) Bacteria
   (c) Spirochetes

III. Real nature unknown: Viruses:—filtrable and ultramicroscopic. Some bacteria may pass through this filterable virus stage. Numerous diseases of man, animals and plants are caused by the extremely small viruses. It is possible the viruses may cause microbes themselves to have diseases. At present, although the viruses are "beyond the microscope," they are being studied intensively.

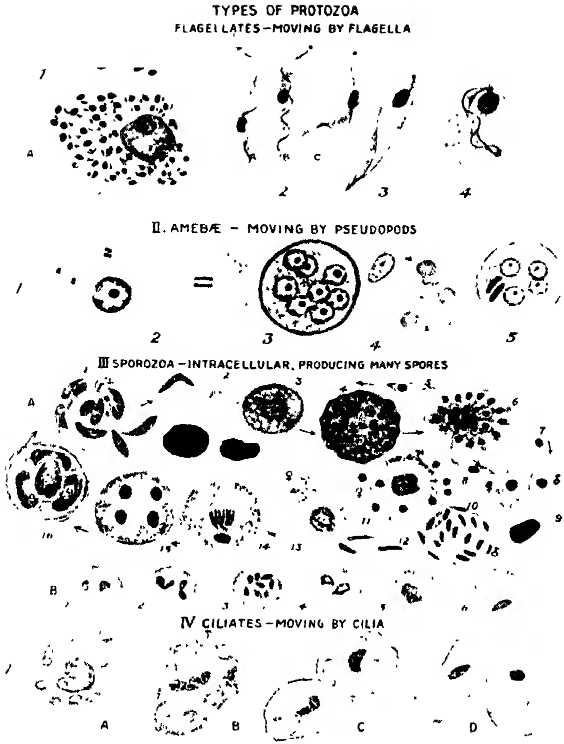

FIG. 9 Disease producing protozoa (I) 1 Leishmania, cause of Delhi boil, oriental sore, 2 and 3 Trypanosomes, cause of African sleeping sickness and diseases of animals, 4 Trichomonas, possible cause of some minor diseases; (II) 1, 2 and 3 Endamoeba coli in different stages The cyst (3) contains 8 nuclei; 4 and 5. Endamoeba histolytica, cause of amoebic dysentery The vegetative form (4) contains human red blood corpuscles. The cyst (5) contains 4 nuclei, (III) Sporozoa of various types The series B 1 to 6 shows stages of a piroplasm in red corpuscles in tick fever (IV) Ciliates. Balantidium coli, sometimes the cause of dysentery (From "Pathogenic Microorganisms," by W H. Park, A W. Williams and C. Krumwiede. Lea and Febiger, Pub , Philadelphia, 1929.)

CHAPTER II

MICROBES AND THE SOIL

The living and life sustaining earth is the thin outer layer of the crust of the globe. This layer, varying in depth from a few inches to twenty feet, is the soil. It is composed of the granulated debris and compounds of weathered rocks, percolated with watery solutions of chemicals and mixed with the excrements and bodies of animals and plants. These dead elements of the soil have been known since ancient times. But its vastly important living characteristics were not recognized until the students of microbes put soil under their microscopes and into their culture tubes. They found it teeming with a huge population of all sorts of microscopic creatures, chief among which were the unicellular animal-like microbes we have called protozoa and the unicellular plant-like microbes we have called molds and bacteria. It is difficult to say how important the protozoa may be in the soil. It is certain that the yeasts, actinomycetes, molds and bacteria there do many useful things and a few harmful ones. In fact, there is abundant evi-

dence to show that these microbes in the soil are so important that without them life, as we know it on this earth, would be impossible. In decomposing the excrement and dead bodies of animals and plants, they may give the soil an unsavory quality, but at the same time, they remove the carcasses of dead things which would otherwise clutter the earth and they put into circulation again the elemental substances essential for the renewal and continuation of life.

All living organisms require a good many elements as the building stones of their protoplasm. Thirty or more elements have been found in the ash of some cells. The relative indestructibility of elements permits their being used repeatedly and the relatively limited supply of some elements requires their repeated use. Plants build up their substance from the air and soil, with the aid of energy from the sun. Animals feed on plants or animals. Both kinds of organisms live for a time and die. New plants cannot grow from dead bodies of animals or plants, and plants would not be what they are if they depended entirely upon sunlight, air and earth formed from weathered rocks.

It is obvious that for the age-long continuation of the use of some of the elements, a salvaging and reconditioning process must be in operation.

Here the microbes perform most useful and important functions. By decomposing the bodies of plants and animals and by working over the resulting compounds, microbes unlock the elements from unassimilable forms and put them back into circulation in usable combinations. Among the elements concerned, carbon, nitrogen, oxygen, hydrogen, phosphorus, sulfur, iron, calcium, potassium and sodium are the most essential for living organisms. Microbes have more or less to do with the endless cycle of transformation of these elements from dead compounds into living substance.

The fundamental stages in the carbon cycle are the production of carbon dioxide by all living organisms and the synthesis of carbon compounds by green plants. The supply of carbon dioxide in the atmosphere comes from combustion of all sorts of organic matter, from the burning of coal to the respiration of cells. A small amount of carbon dioxide may come from carbonated rocks, like limestone. By far the greatest amount of carbon dioxide is an exhalation of the soil, partly from the respiration of the roots of plants and largely from the action of microbes which break down complex sugars, starches, cellulose and proteins into water, carbon dioxide and other compounds.

If we could label an atom of carbon, we might find it first in the air, tied up to two atoms of

oxygen, as carbon dioxide. We might follow it into the leaf of a green plant, where under the influence of the energy of sunlight manipulated by

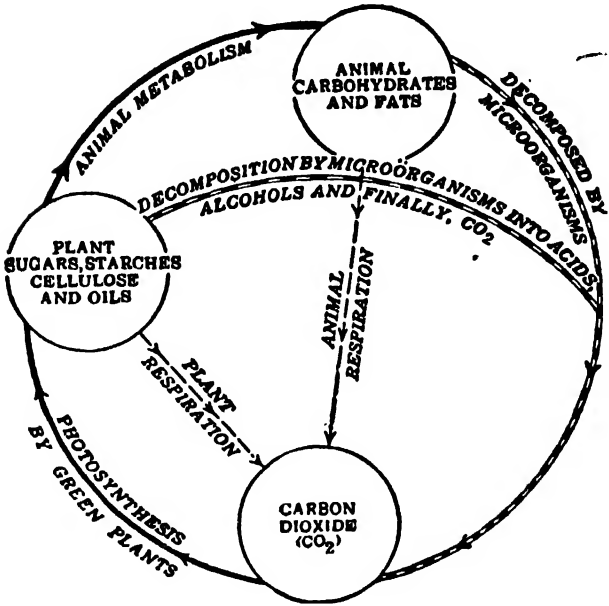

Fig. 10. The carbon cycle in nature, showing the part taken by microbes. (From "A Textbook of Bacteriology and its Applications," by C. M. Hilliard. Ginn and Co., Pub., Boston, 1928.)

the chlorophyll, it would be changed into formaldehyde and then into a sugar. From the sugar or some similar substance, it might be built up into

starch or cellulose. It might become a part of a fat or morticed into a huge protein molecule. For a time, it would be part of the structure of the plant, or part of its food supply. It might undergo a startling transmigration into the substance of some animal devourer of the plant. Its sojourn in the sphere of living things might extend through many generations.

Finally, it would return to the earth in the dead body of a plant or animal or microbe. In all likelihood, it would be seized upon next by a microbe, utilized for one purpose or another and be returned ultimately to the air as part of another molecule of carbon dioxide to begin again its circular voyage through the living and the dead. During its residence in the soil, after being liberated as carbon dioxide by a microbe, it might form a union with water, becoming carbonic acid and serving a useful purpose as a solvent to bring substances into the roots of plants. In the long view of nature, this atom would have an eternal cycle of transformations through animate and inanimate substances.

The everlasting round of nitrogen is through a similar, though more complicated, cycle. In this cycle, plants and the animals are predominately the users and storers of nitrogen, while microbes, chiefly certain bacteria, salvage nitrogen and

return it to circulation. In this, the bacteria play a part which seems absolutely essential for the vast drama of life on the earth. A famine in the midst of plenty, would be a few stunted plants and animals unaided by bacteria, struggling for a short

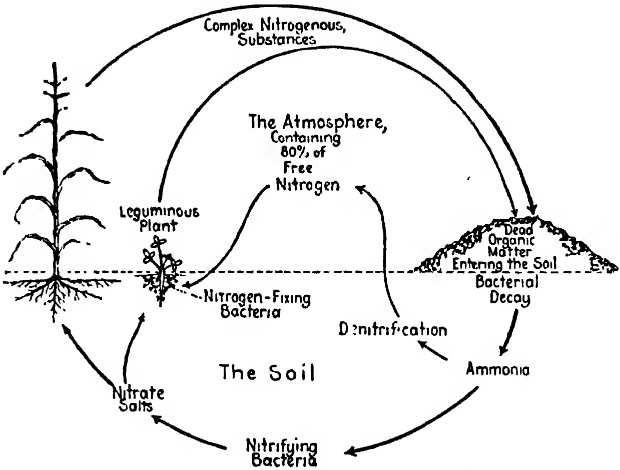

FIG. 11. The nitrogen cycle, showing the part taken by microbes (From "Botany," by E. W. Sinnott. McGraw-Hill Book Co., Inc., Pub. N. Y., 1923.)

time in the atmospheric ocean of nitrogen. Molecular nitrogen makes up about 80 per cent of the atmosphere. Neither plants nor animals can use it in this form, although nitrogen is the keystone of the structure of their protoplasm.

One of the curious characteristics of nitrogen, in view of its essential importance for life, is its inertness in its native molecular state. When, however, it is forced into combination with oxygen and hydrogen, it has a wonderful facility for entering into all sorts of simple and complex compounds. It then becomes an essential constituent of important substances from proteins to dyes, from fertilizers to medicines, from anesthetics to explosives. Slosson has called it the "preserver and destroyer of life." To force nitrogen into these compounds at the start requires the expenditure of great energy. Flashes of lightning produce some oxides of nitrogen. Man imitates this by turning rivers into electricity to give him enormous electric arcs to use in "welding" nitrogen to oxygen, or he burns tons of coal to heat compounds which can unite with the nitrogen of the air. In some processes man uses catalysts to reduce the expenditure of energy.

No process yet invented is as economical as that employed by the lowly bacteria when it comes their turn to influence the cyle of nitrogen. In the soil, atmospheric nitrogen is "fixed" by two kinds of bacteria. One group of these microorganisms lives freely in the soil, and when all conditions are suitable for their growth, they take the inert nitrogen from the air, build it up into their own

bodies and produce some of the nitrates used by plants. The other group forms a partnership with the plant for the business of nitrogen fixation. These bacteria get into the roots of plants through

FIG. 12. Nodules on the Roots of a Legume. Each nodule contains many nitrogen-fixing bacteria. (From "Bacteriology," by H. W. Conn and H. J. Conn. Williams and Wilkins Co, Pub., Baltimore, 1926.)

the root hairs, and develop in cells of the plant root. Where they settle, a nodule forms. These nodules occur chiefly on the roots of legumes,

such as peas, vetch, alfalfa and clover. The relationship thus established is a symbiosis, good for the plant and good for the bacteria. The plant provides some nourishment for the microbes and the microbes, in this nitrogen-compounding factory, furnish essential nitrogen to the plants by taking the nitrogen from the air and building food-stuffs out of it.

Plants store up tons of nitrogen in their bodies and animals feeding on plants simply change the nitrogen storehouse from plant cells to animal cells. During life, animals throw off complex nitrogenous compounds in their excrement. When they die, the nitrogen would remain locked up in their bodies if bacteria did not take a hand in the next salvaging stage. By decomposing these dead bodies and excrements, in the process of putrefaction, the bacteria break down the complex proteins to simpler and simpler substances. One group may carry the decomposition part way and another group may carry it a stage farther, until finally ammonia is produced. Ammonia as such, does not remain long in the soil Nitrifying bacteria use it and produce nitrites and finally the great amounts of nitrates which are the chief sources of nitrogen for plants. In these last stages, the cycle is completed. In the soil, however, there are bacteria which are nitrogen robbers.

A disastrous leakage of nitrogen would occur if the bacteria which return inert nitrogen to the air were to have the upper hand and if their activities were not more than counterbalanced by the bacteria which fix nitrogen.

The fertility of the soil was a great mystery to the ancient agriculturist. He knew that fallowing a field and plowing in leguminous plants enriched his earth. The chemists found out that the soil thus treated gained enormously in nitrogen as nitrates. Finally, the bacteriologist lifted at least some of the veils shrouding the mystery of soil fertility by proving through experiments with chloroformed and heated soils, with microscopes and pure cultures, that the gain in nitrogen was due to the activities of bacteria.

In these days, this knowledge of nitrifying and nitrogen fixing bacteria and the conditions favorable to their growth has been put to great practical service in agriculture. The bacteriology of manures as well as the bacteriology of root-nodules is at the service of man. The preparation of cultures for the inoculation of legumes is a major activity of many bacteriologists in the agricultural experiment stations of states and federal governments.

Sulfur is another essential constituent of cells. In its cycle it journeys "through earth, air and

water," passing from soil into the bodies of plants and animals and back again into the soil. The familiar processes of decomposition by bacteria unlock sulfur from dead cells. Other bacteria in the soil make sulfuric acid and sulfates out of these compounds and pass them on to new plants for their nourishment. At least five groups of bacterial specialists are engaged in the sulfur business. Some are very small. Others form the long threads seen in sulfur springs, where they thrive even more than gullible invalids upon the malodorous hydrogen sulfide, which like so many medicines owes the reputation of its virtues to its bad smell. Still others are gorgeously arrayed in red and purple. Many pick up the sulfur, store it in granules and deposit it in the soil when they die.

In the cycle of iron, the bacteria have some part, though a less spectacular rôle than their part in the cycles of carbon, sulfur and nitrogen. These bacteria have the ability to collect iron. They use the iron for their own energy exchanges and deposit myriads of granules of it in the soil when they die. It seems likely that the deposits of bog iron-ore, which are such a vast source of the iron used in the world, were formed by the iron-collecting bacteria. If this is so, their importance to this age of steel is paramount.

It is absurd to attribute pride of ancient lineage

to uncomprehending germs. But man can look with wonder and admiration upon these microbial pioneers which may be the living representatives of the oldest inhabitants of this earth. Some of the nitrifying bacteria, sulfur bacteria, iron bacteria and a host of others can live on inorganic substances, independently of the life of any other creature. They can take the elements from forms which animals and plants cannot assimilate. They can obtain energy by the shifting of electrons, performing "oxidations" in the absence of oxygen. They could thrive upon a barren earth, dark with misty vapors and in an atmosphere of volcanic fumes, and the deposits of sulfur and iron they have left in ancient geological sediments suggest that they were thriving on the earth before there were any animals or plants. Both their ways of living and their potential antiquity give these microbes of the soil unique interest.

The story of microbes in the soil would not be complete without a mention of the harm some of them are capable of inflicting as producers of disease. Unfortunately for man's self-centered opinion that all things are ordained for his convenience, the impartial soil harbors some of the germs of man's destruction and of the destruction of his valuable animals and plants. Some of the bacteria in the soil, attacking plants, cause rots, wilts, leaf-spots

and galls. Fungi invade the roots of plants, producing root-rots and blights. "Scab in potatoes and sugar beets and pox in sweet potatoes" are due to infections with actinomycetes. Germs of diseases of man and animals, deposited in the soil with sewage, excrements, discharges and the dead bodies of victims of disease, may regain entrance into healthy animals and sicken or overcome them.

Fortunately, many of these disease-producing germs are parasites too delicate to survive in the rigorous conditions of the soil. A few, however, by forming resistant spores, tide over a period of hardship in the soil Of these types, the most important are the germs of anthrax, lockjaw, gas gangrene of wounds, black leg and the sort of paralyzing food poisoning known as botulism. More will be told about these later. The microbiologist can thus compile a fairly long list of disease germs whose temporary or permanent residence is in the soil. In doing so he has rendered man another service. The germs are found to be living creatures with vulnerable spots which man can attack in his campaign to control disease and the vague ancient superstition of contagious exhalations and miasms rising from the soil to spread pestilence has been dispelled.

CHAPTER III

MICROBES IN AIR, WATER, AND SEWAGE

IN THE heavens above and in the depths of the earth water is usually free from microbes. All the collections of water close to the surface of the earth usually contain many kinds of microbes. The importance of this, from the point of view of our story of microbes and man, comes from the use of rain-barrels, cisterns, springs, streams, wells, ponds and lakes as sources of drinking water for human beings. To understand what is involved in safe-guarding drinking water, it is necessary to find out the sources from which microbes get into water, what becomes of them after they get there, and what man can do to exclude the harmful germs and put others to good use. It may shock the sense of niceness to find drinking water and sewage linked in the same sentence. Unfortunately, the two are so often found in the same glass that a consideration of one cannot be taken up without a mention of the other. The courses of water supplies and sewage disposal will take us into one of the most important phases of modern sanitation.

Some kinds of water have special populations of unicellular organisms. The indigenous inhabitants of sea water, fresh water and even of hot springs are interesting native microbes. In some situations they form deposits of compounds useful to man. In the seas, the algae and diatoms, serving as part of the food supply of fish, help to build up the food man lives on and perhaps are a source of the vitamins in cod liver oil. For milllions of years, the flinty and chalky skeletons of these small creatures, raining down upon the sea bottom formed the deposits which man now uses for abrasive grinding powders, the manufacture of filters and for chalk and lime.

In lakes and streams, an overgrowth of algae may use up so much oxygen that the fish are suffocated. In reservoirs, some of the algae and diatoms may liberate such malodorous and bad tasting substances that human beings shun the water as if it were poison. Many of these organisms are exquisite creatures, with geometrical patterns more beautiful than snow-flakes. All of them are interesting. By definition, however, we decided to leave them out of the group of microbes having the greatest importance for man.

The spores of bacteria, molds and protozoa are so light that gentle currents of air are sufficient to swirl them up and to keep them suspended in

the atmosphere. A few of the vegetative forms may survive short periods of drying and have a temporary flight in the air above the earth. As air is not a sufficient medium for the growth of microbes, there is no multiplication of germs in it. Fortunately, the germs of most diseases are too delicate to survive in the air alone. Although these germs may travel for short distances in the air of sick-rooms, or somewhat longer distances when wafted along enclosed in a protective envelope of dried pus or sputum, in a small particle of infectious dust, they are not of great importance in long distance aerial transmission of disease.

A rain-drop starting in the high clouds has a great chance of beginning free from germs. As it falls, it collects dust and spores. By the time it reaches the earth it may have swept out many microbes from the air, to contribute them to the cistern or whatever other body of water it may ultimately reach. The germs thus added to sources of water are not of much importance in the spread of disease. They are, however, partly responsible for the total number of microbes in a sample of water and cause genuine misery for all those working with chemical processes, fermentations and the manufacture of articles, all of which can be spoiled by the growth of microbes from water.

Microbes by the millions are washed from the soil into water. Some of the native earth-inhabiting germs may not do so well in the new element. Others, given the right conditions of temperature and oxygen supply, easily take up an aquatic life and thrive in waters containing food-stuffs suitable for germs, which we have seen may be anything from the carcass of a cat to shreds of grass. These microbes of decomposition in water can reduce tons of the cast-off bodies of animals and plants to simple compounds, digesting almost everything from skin to cellulose. The army of scavengers which man uses to help clean up his sewage is largely recruited from these hardy analytical microbes.

The other group of microbes which can pass from soil to water are natives of the intestinal tracts and bodies of both normal and diseased animals and man and are really only transients in the soil. It is obvious that they get into the cultivated soil and the earth around human and animal habitations chiefly from the dumping of excrement in and upon the soil, either for the purpose of fertilization with manure or from the use of the soil as a convenient receptacle for excreta. The chief water-born diseases of man are produced by germs from this source. While there may be some question as to what and how many diseases can

be carried in this way, there is no question but that the chief are cholera, typhoid fever and dysentery. With the exception of the type of dysentery caused by the protozoan amoeba, these diseases are due to intestinal bacteria. In plain language, when a person contracts typhoid fever or dysentery from drinking water, it usually means that the beverage has been more or less contaminated with human excrement passing indirectly from the soil into the water or directly from the dumping of sewage into water.

The disposal of sewage by water is an ancient custom. It has been followed by man wherever he settled near a convenient stream or body of water. It is likely that, for esthetic reasons, man has made an effort to avoid contaminating his own water supply. But his habit of using water to wash away excrement is much older than his knowledge of the invisible microbes which cause intestinal disease. He was ignorant of how to protect himself and his neighbors—if he cared at all about them—from the germs put into the water with his sewage. Even now, with a full knowledge of the consequences, individuals and communities continue to act as if they were guided by the old adage, "out of sight, out of mind," and continue to let disease-bearing sewage get into water, which though clear of all visible particles of excrement may be full enough of germs.

In the search for sewage contamination, or fecal contamination of drinking water, the bacteriologist does not look for the germ of typhoid or the germs of dysentery. These microbes are usually so few in numbers that they are overgrown by hardier bacteria in the samples examined in the laboratory. They have been found occasionally in these samples by luck or by workers more skilled than those who can find needles in haystacks. It is enough for the bacteriologist if he can find in water one of the microbes he is fairly sure comes from the human or animal intestinal tract. He searches, therefore, for the colon bacillus, a relatively hardy microbe excreted in millions by animals and man. If he finds this germ in water, he can say that the water is contaminated by excrement from animals or man.

This sort of information, which the bacteriologist can give from his cultures, is the foundation of many of the measures used in the sanitary control of water supplies. If the results are positive, they are worth a great deal. If they are negative, they cannot be used to give a clean bill of health to water. A sanitary survey is essential to determine whether a well, spring, lake or stream is likely to be contaminated even at times when the bacteriologist fails to find colon bacilli in the samples.

This sort of bacteriological detective work helps

also to secure oysters and other shellfish, which are both palatable and free from dangerous sewage.

The problem of the disposal of sewage starts on a small scale with the individual man and increases to great proportions with the increase in the size of the communities of men. Earth-burial of excreta and the dumping of excrement into bodies of water may serve the purposes of a remote group of men living in a sparsely settled region. But when the population becomes dense, with settlements ranging from villages to great cities situated on brooks, or rivers, or lakes or arms of the ocean, what to do with the material and microbes shed from the intestines of man is a very serious affair.

The microbes may be killed by burning up the material. It is possible to incinerate a vast amount of valuable garbage, but totally impracticable to burn the billions of gallons of the excrement of thousands of persons. Burial in the earth does not serve, because the soil then becomes a foul bog of putrescence and a prolific source of pollution of drinking water. The dumping of the material into bodies of water is still the most common and convenient method of sewage disposal, in spite of the fact that this provides a reflux contamination of the water of those who polluted it and a dangerous stream of microbes pouring into others elsewhere who have to drink it.

Of course, filtration and disinfection with chlorine and other agents can rid polluted wastes of most of their menacing microbes. While this is a safeguard, it does not protect everyone, and should be less and less necessary as communities of men gain the conscience and the knowledge and the means for the proper disposal of their sewage.

Aside from important physical problems connected with the handling of sticks, logs, fats and the collection of insoluble articles in sewage, and aside from important chemical problems connected with bad tasting and poisonous industrial wastes, the problem of sewage disposal comes down to the use of microbes to digest, decompose, deodorize and clear the material, and to make conditions too hard for the survival of disease-producing germs. The huge sewage disposal plants of some cities are in reality man-made factories for microbe workers. In settling tanks, certain groups of bacteria begin to break up the material. In septic tanks or Imhoff tanks, with air excluded from the depths, the anaerobic bacteria tear apart the sewage substances in their own way. In long seething aerated troughs, inoculated with activated sludge, and in trickling filter beds made of pieces of stone coated with bacterial slime, nitrifying bacteria and other organisms reduce the compounds to ammonia and simple substances.

Finally, the fluid flowing from a sewage disposal plant in which these microbes have been given every opportunity to do their work, may be like clear water. It can be passed into a stream or lake without danger to these sources of the supply of drinking water.

A remarkable general improvement in health has occurred in communities where polluted water was replaced by a supply of good drinking water. Freedom from diseases known to be carried by water brought with it reduction of diseases not directly associated with water. The triumph over a special group of microbes seems to have aided man in victories over others. His continued safety, however, is dependent upon eternal vigilance. Some of the most serious water-borne outbreaks of typhoid fever have occurred recently in communities provided with the apparatus for obtaining safe drinking water. In those cases, neglect or accident mixed sewage with drinking water and set a modern stage for an ancient drama of sickness. They are sad but forceful new examples of the relationship of microbes to the fate of man.

CHAPTER IV

MICROBES IN INDUSTRY

IN ONE sense, microbes are living chemicals. They renew themselves while carrying out hundreds of reactions, building up new products and splitting off valuable compounds from wastes and residues of animals and plants; and from inorganic substances. Man began to take advantage of these activities of microbes in his early agricultural and domestic ventures. He knew how to enrich his fields by plowing in certain plants. He found out that leavened bread was one of the best of nutriments, and he discovered, to his delight, that the juice of the grape, left alone, took on a new exhilarating quality after a period of seething turbidity. These were instances of mysterious fermentations, not at all understood until the bacteriologist looked into them during the last century.

Many of the "natural" industrial processes employed by man were found to be unconscious utilizations of microbes.

At present, numerous kinds of bacteria and a few yeasts and molds are being employed in

industries in which millions of dollars are invested and from which millions are gathered in profits.

Microbes are used: (1) for the fermentation of carbohydrates (sugars, starches, cellulose); to produce carbon dioxide for bread raising, supply soda water fountains with gas and for the CO_2 used in many ways; to produce alcohol for industrial purposes and for wine, beer and other alcoholic beverages; to make organic acids, such as acetic acid in vinegar and lactic acid in dairy products; to provide acetone, butyl alcohol and glycerine for use as solvents, explosives and other chemical purposes; (2) in agriculture to enrich the soil with nitrates and for nitrogen fixation; (3) in textile industries for the retting of hemp and flax and for their part in sizing and indigo fermentation; (4) in the curing of hides and the tanning of leather; (5) in the enormous dairy industry, for the making of butter, cheese and soured milk products; (6) in the coffee, cocoa and tobacco industries, for digesting the covering of seeds or for the curing of leaves; (7) in the preparation of enzymes; (8) in the actual growth of food in crops of edible yeast and (9) as a source of some of the vitamins.

In addition to these uses of microbes, their presence in products establishes the conditions under which huge industries have to be conducted. The greatest of these are the preserved food indus-

tries, which depend upon vast refrigerating systems or heating and canning processes to keep down the destructive growths of microbes.

The industrial use of microbes thus has two sides. On one side, the industries are built upon the utilization of microbes; on the other, they are built upon the exclusion or suppression of microbes. In practice, this division is never sharp. It is always necessary to keep any bacterial process free from contamination with undesirable microbes, or to set up conditions which will allow one group to flourish to the disadvantage of other groups, or to kill off all microbes by heat and then seal up the products in impervious containers.

While the list given in the last paragraph does not include all the industrial applications of microbiology, it does indicate that man is using microbes in many ways in his business. It indicates also that those who attend to the microbes at work in vinegar barrels, silos, fermentation vats, cheese ripening rooms, dairies and canning factories and many other places have none too easy a time in the practice of their microscopical horticulture. They are likely to have to solve problems of general scientific and human interest. Instead of summarizing the details of many bacterial processes used in the industries, it will be more to the purpose of this generalized sketch to look into the

principles and characteristics of a few of the industrial applications of microbiology.

Under the existing laws of this country, it would be improper to place a compendium of the making of wine and beer in this book. It is obvious, however, that this very ancient, human application of microbiology is of enormous economic importance in other countries. It must be admitted that even in the United States today the microbial preparation of alcohol is of great sociological and economic significance through the legally recognized business of the production of industrial alcohol and through the activities of a host of professional and amateur fermenters.

In any case, the conversion of sugar into ethyl alcohol by yeast is a process of such fundamental scientific significance that mention of it cannot be omitted without loss. Yeast and a few molds are able to change the glucose of grape juice and the maltose of malt into ethyl alcohol and carbon dioxide. In the natural fermentation processes, the source of the yeast is the fruit or grape. When the grapes are ripe, yeast is usually present on the skins. The proper yeast may be in the vineyard or it may be introduced into the grape juice by inoculation. Inoculation of malt with the right sort of yeast is the chief method of assuring the desired sort of beer. When yeasts grow in these

sugary fruit and grain juices, they become most intricate chemical factories. While alcohol and carbon dioxide gas are the main end products, many other chemical reactions, taking place in the fermenting fluid, yield many different substances, such as glycerin, organic acids, "fusel oils" and aromatic and flavorous substances. Studies of the utilization of sugar by yeast have thrown some light on the way human and animal cells handle sugar, and may do more yet to explain the metabolism of normal cells and of the abnormal lawless cells composing cancers.

From old times to the present day, wine makers and beer makers have lost batches of their brews because of abnormal fermentations. They have seen a fermenting liquid develop a scum and become cloudy when it should have cleared. Palatable and aromatic liquids have become bitter, rancid, or sharp and developed bad odors. About seventy years ago, in France, these maladies of beer and wine were causing such great losses that the vintners and brewers asked for help from Pasteur, the founder of the rising science of bacteriology. After years of investigation, Pasteur proved that those disorders of fermentation were due to the overgrowth of yeast by bacteria which produced acetic and butyric acids and in some cases by the germs of putrefaction. In the

course of these experiments, he showed that heating the wine to about 145°F. would destroy most of these germs and secure the preservation of the product. The familiar process of pasteurization, used for preserving wines and milk nowadays, came from these investigations. Many other useful things were learned about the effects of oxygen, temperature and the supply of nutriment.

A great part of the foundation of the science of bacteriology was laid in Pasteur's investigations of fermentation and the diseases of beer and wine. Out of his scientific attack upon the practical troubles of the makers of alcoholic beverages came conceptions and experiments which fitted directly into a germ theory of disease of plants, animals and of man. In the first place, the demonstration that a particular microbe produced a characteristic end product led to a notion of the specific actions of bacteria. In the second place, since it was proved that the diseases of wine and beer were due to certain bacteria, was it not logical to suppose that diseases of animals and plants could be brought about by the activities of other specific microbes?

The years following these studies yielded discovery after discovery proving the soundness of this point of view. They were a brilliant period in the search for the causes of infectious disease.

The technical mycologist may not approve of this digression into medical bacteriology as an attempt to add importance to the intrinsic significance of his part of the science. But the historical development took place in this way, justifying the statement made by Robert Boyle in the seventeenth century, that the man who discovered the cause of fermentation would learn a great deal about disease.

Two other fermentation processes which bring this side of microbiology into the home are the making of vinegar and bread.

If wine or hard cider is desired, the change of alcohol into acetic acid is a catastrophe. But if vinegar is required, this conversion is essential. It is usually brought about by inoculating alcoholic solutions, such as wine or fermented fruit juice, with "mother of vinegar." The "mother of vinegar" is a slime composed of millions of mothers of acetic acid, millions of smaller or larger bacteria which have the power of changing ethyl alcohol into acetic acid. To do this, they require a large supply of oxygen. Hence vinegar barrels, Pasteur vats and the German cylinders full of chips of beech wood are all devices to aerate the alcoholic liquid while the bacteria are acting upon it. Like any other fermentation product, vinegar is subject to "disease." If undesirable bacteria

claims for its other medicinal properties, though supported by testimonials, are not yet established. Finally, yeast under certain circumstances, may become an important item of food supply of man and cattle. In fact, the domestication of the yeast may some day turn out to be as important to man as the domestication of the cow.

Milk is universally recognized as one of the most important food-stuffs of man. In the United States alone, he collects more than twelve billion gallons of cow's milk every year. Even in the face of this record, man is being urged to use more milk. No such propaganda seems needed to further the consumption of milk by microbes. Among the microbes, the bacteria, yeasts and molds, have a "keen appreciation" of the nutritive qualities of milk. So many kinds of them can thrive on milk that they could easily dispose of many times these yearly billions of gallons of milk.

If milk could reach the consumer in the same condition in which it exists in the udder of a healthy cow, the only importance microbes would have for the dairy industry would be that due to their ability to help in making butter and cheese. But diseased cows exist and shed their germs through their udders, diseased milk handlers can scatter their particular harmful microbes into milk, and manure-specks, dust, milking machines, pails,

tanks, pasteurizers and bottles can contribute their quotas of microbes. In view of these hazards, it is wonderful that milk can be brought to the consumer in anything like its original condition. Many producers of milk succeed in approaching this ideal; other handlers of milk must be forced by stringent regulations to produce a safe milk. It seems probable that in the past, more cases of disease have come out of glasses of milk than from any other food consumed by man.

The applications of microbiology in the dairy industry, therefore, are seen to have two main lines: first, the exclusion of bacteria from milk and the killing of as many germs as possible, chiefly those of disease, which may have gotten into milk. This phase extends into veterinary and human medicine, the care of the health of cows and supervision of the health of milkers. Second, the use of special microbes in the making of butter and cheese and soured milk.

One way of grading milk is based upon counting the number of bacteria in a small sample. The bacteria may be counted in specimens prepared and stained according to Breed's method. As the dead germs stain as well as those living at the time when the preparation was made, this method permits the enumeration of all the microbial "villains" present at any time in the sample. Another way

is to count the living bacteria by noting how many colonies grow on a plate culture of nutrient agar medium mixed with the sample. Each colony may be formed by the progeny of one microbe or of a cluster of bacteria. Both methods are useful. If a very dirty milk were heated in the pasteurizer at 145°F. for 15 to 30 minutes, the plate count might be quite low, because most of the bacteria had been killed, while the Breed count would be high, because the bodies of the cooked microbes would appear in the stained specimen. The total number of bacteria gives a fair idea as to the care used in the process of collecting and handling milk. Good certified milk has a low bacterial count, while "bootleg" milk may contain a billion or more bacteria in a cubic centimeter. These counts, however, tell little or nothing about the germs of disease which may be found in the milk. These are so difficult to find, and difficult to grow that they are looked for directly only where need for a special investigation arises.

At those times, when a milk supply is suspected of being the source of tuberculosis or undulant fever, or epidemic sore throat, special methods of culture and the injection of milk into animals must be resorted to in order to find the few killers lurking in the milk. Much can be said in favor of the pasteurization of all milk on the basis of the

uncertainty as to whether or not any one sample of raw milk is free from all germs of disease. Properly conducted pasteurizing and subsequent clean handling of the milk will usually assure a supply of milk free from the germs of tuberculosis, typhoid fever, sore throat, undulant fever and some other diseases. This does not mean that a pasteurized dilution of cow manure in milk would always be preferable to the cleanest certified milk, but it does suggest that milk produced under the cleanest conditions permitted by its cost and then pasteurized properly would be almost ideally safe. In the preservation of milk, disinfectants are not allowed and are undesirable. Dependence must therefore be placed upon cleanliness in handling and pasteurization.

The control of milk extends to the supervision of the health of the cattle and medical supervision of the milker and milk handlers. The first part is a veterinary problem of relatively easy solution. Cows can be tested for tuberculosis—and slaughtered by law. If cows have other diseases, like infectious abortion which is transmissible to man in the form of undulant fever, they can be gotten rid of in one way or another or segregated. A cow with inflammation of the udder, mixing its milk with pus and the germs of epidemic sore throat, can be removed by order from the milking herd.

The medical inspection and supervision of milkers is a more difficult problem to solve because its solution involves questions of personal liberty. Some milkers work while they are sick, and transfer their germs of sore throat or diphtheria by means of their hands to the milk. Other milkers may be quite well and yet carry the germs of disease in their systems. Some of these are carriers of typhoid fever germs, which are transferred to the milk through the hands of the milker or milk-handler. Laws, regulations and compensation are available to prevent such diseased individuals from handling food, but in the names of liberty and the necessity of earning a living they are at times evaded.

Milk itself is susceptible to many types of spoilage. These "diseases" of milk, ropy and slimy milk, red, yellow and blue milk, sour, rancid and putrid milk, are all due to the overgrowth of microbes which would do little or no harm to living animals, but can decompose a bottle of milk.

The useful bacteria and molds in the dairy industry were found in the starters used to make butter with special yield and flavor, to make all varieties of cheeses and to prepare the sour milks. When cream rises, it includes many bacteria. Numerous others come from the starters added to sour the cream before churning and to give certain

flavors to the butter. Butter and cream contain many bacteria, usually of the harmless types.

Cheese-making is an enormous microbial industry. The statue recently raised in France to the founder of the Camembert business, might with equal propriety have acknowledged the part played by bacteria and molds in the confection of this delicacy. Each region noted for a special cheese is in reality made famous by what its peculiar local mixture of bacteria and molds fabricate from a curd of casein and lactose.

Some years ago, when Metchnikoff noted that the chief article of diet of some long-lived Bulgarians was a soured milk, he made a bacteriological study of their reputed elixir of life. In it he found a definite type of lactic acid producing microbe. Continued study of organisms like the one found in the Bulgarian milk led to the recognition of a type known as *Bacillus acidophilus* which seems to be able to accommodate itself to the human large intestine and is used, for medicinal reasons, in the preparation of "acidophilus milk." The drinking of acidophilus soured milk may be salutary in some cases. But it would be an amazing and trite ending of a romantic quest if the fountain of youth were to be found in a glass of sour milk.

In the drying, pickling, salting and smoking of meat an acceptable type of embalming is combined

with the destruction of many microbes. Where none of these processes are applicable cold is used. The meat is kept in refrigerators below a temperature at which most of the bacteria and molds can grow. To those engaged in the food preserving industry, the existence of microbes must appear to be a calamity. But for those whose business is the making of cans and refrigerators, pressure sterilizers and ice, the microbes are a boon.

Similar problems confront the preservers and canners of fruits and vegetables. They are forced by the ever-present microbes to take extraordinary pains to keep their products from spoiling and to prevent them from causing disease.

Sometimes—fortunately very rarely—the canning, pickling and preserving processes are not well enough done to destroy all disease-producing organisms. Sometimes, the food, like meat sausage, is not treated in the manner required to kill these germs. At other times, the food, after removal from cans is contaminated by droppings from rats and mice, by wipings from the germ laden feet of flies, or from the microbe soaked fingers of some moderately healthy carrier of disease. In this way, outbreaks of food poisoning and infection from food occur. The most dangerous type of food poisoning has occurred occasionally from the consumption of food

containing the poisons of a germ, the spore of which survived the temperature of processing or the brine of pickling, and was able to grow and produce its fatal toxin under the airless, anaerobic conditions in the can or jar. This type of food poisoning is called botulism because the germ giving rise to the poison was dignified with the Greek name for sausage, in which it was originally found. The poison affects nerve centers, producing finally paralysis of the breathing center. The poison can be destroyed readily by temperatures used in cooking. It is often swallowed, however, with canned vegetables like olives, string beans or asparagus which are served cold.

The professional food preservers use every effort to prevent botulism. Outbreaks, unhappily, have occurred from the ingestion of home-canned products, put up by someone whose industry was greater than her knowledge of microbiology. The pride of a home-canner or the politeness of guests have led to fatal botulism after repasts composed of food with a slight odor of taint which everyone was too polite to mention.

The other chief type of food poisoning is a severe irritation of the stomach and intestines, associated with vomiting, cramps, diarrhoea and collapse. A number of organisms which get into prepared foods may be responsible for these effects. This

used to be called ptomain poisoning. That term is being abandoned now, and it is usually supposed that bacteria resembling paratyphoid bacilli are directly responsible. "Revamped" foods, like hash, and partly cooked foods, like custard pies, are the main vehicles of this sort of disorder.

Celebrations in which charitable and unstinting, but unsanitary, service in the preparation of the food to be eaten on the picnic or at the wedding party, are often the sad occasions of outbreaks of this sort of food poisoning. The infections from foods may be so numerous that it behooves all those supervising the industries of food-serving to insist on a clean bill of health from their cooks and food-handlers. The train of misery and death left by "typhoid Mary" in her journey from kitchen to kitchen in this country is an example of the wreckage produced by an uncontrolled carrier of disease engaged in the food business.

It would be lugubrious to continue to catalogue the instances of spoilage produced by microbes, although the longer list would increase their sinister prestige. They can grow on leather and glue, in photographic emulsions and between the elements of the lenses of cameras, in fish-ponds and parlor aquaria, in the thin film of moisture close to grains of sugar and in the brine vats of salt fish.

In all of these locations, they cause deterioration of the object on which they grow. In an earlier chapter we praised these activities as denoting the conservative actions of bacteria in the cycles of the elements. In that respect they are beneficial to man. But when man is not ready to have himself, his enjoyable animals and plants and his toys and perishable instruments decomposed into compounds available for some stage in the cycle of the elements, he condemns these microbes as pests. In both cases, the microbes remain more or less the same, and retain their vast importance. What man thinks of their activities depends partly on his point of view—at the moment.

CHAPTER V

MICROBES AND PLANTS

PLANTS are no more exempt than the higher forms of life from the tyranny of microbes. They struggle in their own ways under the beneficent despotism of the helpful germs and against the persecution of the destroyers. When we examined the microbes in the soil, we found many bacteria and fungi changing organic residues to nitrates and other compounds on which plants feed. We found, also, millions of small germs in the nodules on the roots of legumes, working with plant cells to make nutritious compounds from the inert nitrogen of the air. We called the last sort of relationship a symbiosis, because the partnership was good for both the microbes and the plant. But it was also perilously near a condition of disease, as shown by the nodular reaction on the part of the plant.

Aside from the good done by the residence of nitrogen-fixing bacteria in the nodules of legumes, the invasion of plant tissues by microbes is usually harmful. It is true that the diseased foliage of some plants is regarded as sufficiently ornamental

to have a special commercial value, and that some of the more highly prized varieties of tulips are diseased. Man profits by the sale of such specimens. There is no evidence that these diseases benefit the plants. Both plants and man lose vastly by the attacks of all the types of microbes upon almost all varieties of plants. These losses affect individual farmers disastrously and may endanger the economic and social arrangements of great communities through the destruction of the wheat, cotton, potato or citrus plants which furnish the staple crop of that section. Since we have already shown microbes at work in aid of plants, this chapter will have to do chiefly with microbes at work in the injury of plants.

The observations made upon diseases of plants due to molds and fungi antedate the observations upon diseases of animals and man due to microbes. After the middle of the last century, however, the scientific side of this knowledge of plant diseases advanced along with the development of bacteriology. Discoveries of the nature of infectious diseases in one group of living things contributed to the knowedge of infections in other groups and there has always been a beneficial exchange of information and ideas between the plant pathologists and the animal pathologists. At first glance, this may seem strange, when the differences between

plants and animals are considered. The rigidity of cell walls, absence of a blood circulatory system, fixation in the earth and mode of nutrition make plants superficially very different from the relatively plastic animals with their circulating blood, their ability to move around on the surface of the earth and their diet of organic matter.

Beneath these differences, however, animals and plants share fundamentally similar cellular structures and capacities for reactions. In the age-old processes of disease, there are so many close analogies between the behavior of plants and animals that it is after all not surprising that what is known about one of these forms of life should be helpful in solving the mysteries of the other. The defensive reactions of plants against invading microbes are somewhat different from those of animals, chiefly because plants lack the circulating blood fluids and blood cells which play so important a part in the immunity of animals. Nevertheless, it is not at all improbable that a germ theory of disease applicable in general outlines to the infections of animals could have been deduced from studies of the effects of microbes upon plants.

Plants are susceptible to attack by representatives of all the chief classes of the microbes which produce disease in animals. For some time, how-

ever, it was not admitted that plants suffered from bacterial diseases. Progress in this part of the science began in 1880, when Professor T. J. Burrill, of the University of Illinois, announced his discovery that pear blight was caused by bacteria. The universal doubt with which this statement was received was entirely dispelled by the researches of Erwin Smith, who, after a life-time of study proved his prophesy that there were "in all probability as many bacterial diseases of plants as of animals." The record makes a great chapter in the history of American contributions to bacteriology. Among all the bacterial wilts and rots and blights studied by Erwin Smith, the crown galls received his greatest interest in his later years. These growths resemble in some respects the cancers or tumors of animals. They were shown to be produced by bacteria and bacterial or chemical substances which caused the plant cells to start on a career of overgrowth, like animal cells in cancers. No one has ever proved that a germ causes human cancer, although some investigators are following leads in that direction, encouraged by these studies on plants. It seems likely that no general similar conditions exists in animals tumors.

Diseases due to microbes are transmitted from plant to plant in much the same ways in which they are spread among animals. The nurturing

soil also harbors the germs of destruction and microbes of disease enter plants from soil. Contact between plants, the carriage of germs by dust, by insects, by birds and by animals and man serve to spread infection among plants, just as similar agencies do the same thing among animals. Quarantines of plants, exclusion of infected plants and seeds, isolation, destruction and disinfection are measures used to check the spread of these diseases. These measures have a familiar sound to those who are trying to guard the health of animals. Plant sanitation and animal and human sanitation are governed by the same general laws.

In most communities of living things there are hardy individuals who survive one sort of pestilence or another. Disease resistant races can be bred from such stock. In the cases of animals and man, this quality of resistance of disease may be coupled with undesirable attributes of mind or body, and while selective breeding of animals is a practical procedure in some respects, selective breeding of man has not yet sufficient certainty of knowledge or sanction of society. Some plants, however, can be selected and bred with direct reference to their ability to resist disease. Rust-resistant wheat and cabbage resistant to "yellows" have been selected and cultivated successfully in

infectious areas, giving encouraging evidence of what may be accomplished some day through the progress of this eugenic phase of "preventive medicine."

Parasite and host relationships among the plants are sometimes as definite as they are among the animals and their particular microbes. One way of regarding these relationships is to look on a species of plant as peculiarly susceptible to some particular variety of microbe. The other way, and the one which has the greater probability, is to look at the situation from the point of view of the microbe. The microbe seems to be capable of adapting itself to the particular conditions offered by a certain species of plant.

In the early nineties of the last century, a startling discovery was made by the "phytopathologists," Ivanowski and Beijerinck, who were studying the mosaic disease of tobacco. They recognized that this was an infectious disease, transmissible from plant to plant by inoculating a healthy plant with a small drop of fluid from a diseased leaf. In this fluid they were unable to find any sort of visible organism. Nevertheless, the infectious agent seemed to be able to perpetuate itself indefinitely in the successively inoculated leaves. It was discovered that this disease agent could pass through the pores of unglazed porcelain

filters which prevented the passage of ordinary bacteria. Here was an infectious fluid, containing either living matter in an unorganized fluid state, or in particles too small to be seen by the best microscopes, or else it was "dead" material in solution capable of causing the plant to liberate a disease inciting substance with self-perpetuating properties.

This discovery by those studying diseases of plants opened up a vast territory, not yet thoroughly explored, occupied by the so-called filterable viruses. These viruses are responsible for some of the most deadly diseases of man and animals, as well as many destructive diseases of plants. They are responsible for much ingenious experimentation and for philosophical and scientific conceptions of life. Although these viruses are "beyond the microscope," we shall see something of what they do later.

Plant sanitation based on preventive measures is better than attempts to cure diseases. The increasing realization of this truth is benefitting horticulture, agriculture and forestry just as preventive medicine is safeguarding the health of animals and man. Nevertheless, vast sums are expended on patent medicines for plants. Some of the sprays used are effective and essential. Others could be well dispensed with and the money

and effort now given to their use devoted to attempts to prevent disease.

Only a few of the diseases of plants are harmful to animals and man, and these harmful results come from the consumption of poisonous substances produced by microbes in the plants. The chief of these is the ancient Saint Anthony's fire, which at one time seemed to spread like an epidemic in Europe. It is produced by ergot, a poison elaborated by a fungus growing in the heads of grains and grasses, chiefly rye. The black spurs in the heads of blighted rye contain a substance which causes long continued spasms of blood vessels and the contraction of smooth muscle. Too much of its leads to gangrene, from cutting off the circulation. A proper amount of it aids the contraction of the uterus. Ergot has given such a useful service in the aid of childbirth that even this potentially poisonous product of a microbe has turned out to be advantageous for mankind.

CHAPTER VI

MICROBES AND INSECTS

WITHOUT microscopes or culture tubes, the insects have made use of a few microbes. If we granted intelligence to insects, we would have to call some of their doings "clever applications of microbiology." Some insects have body cells packed with bacteria which seem to be carrying on something important for the life of the insects. The most skillful insect "microbiologists" are the termite ants. These keep certain protozoa in their intestines to help digest the wood fibers they eat and in their huge ant-castles they have gardens for the rearing of the particular sort of mold they use for food. They seem to have a taste for a special sort of microscopic "mushroom" and they take great care to cultivate this fungous delicacy.

Many a bee-hive has been robbed by microbes. The germs, however, are not after the honey, but seek the succulent bodies of the larval bees. The American and European types of foul-brood are caused by bacteria. The other disease of larvae in their waxy cells, called sac-brood, is due to one

of the still invisible filterable viruses. Infection probably comes into the hive by food, and can be spread by contact and by hive tools. The diseases are destructive and can be stopped at times only by burning the infected hives. Although the adult bees resist many germs, they are susceptible to stomach and intestinal troubles produced by a sporulating protozöon.

The touch of microbes makes the whole world kin. We have seen that the understanding of human infectious diseases came partly from studies of sour beer, partly from studies of wilts of plants and now we shall see that some of it came from studies of sick silk worms. After 1835, the diseases of silk worms became so devastating in France that the immensely valuable silk industry was in danger of destruction. Even in China, silk worms became sick and died and at one time uninfected eggs could be obtained only from Japan.

Soon after the middle of the century, when the science of bacteriology was just beginning, Pasteur was entreated to leave his laboratory in Paris and go into the silk worm districts to try to find out why the larvae died before they spun their cocoons and to try to find some way of preventing the disease. After five years of extremely difficult work, exploring the unknown, suffering from illness and discouragement, Pasteur unravelled a double

mystery. He found that the silk worms had two pestilential diseases. One, called flacherie was caused by a bacterium. The other, called pebrine, associated with peculiar corpuscles in the bodies of the larvae, turned out to be due to an animal microbe, like the protozöon *Nosema* of bees. Pasteur showed how to select healthy larvae and how to prevent the spread of the infections. He rescued the silk industry. At the same time he established proofs of microbes as agents of disease, which, though drawn from cases of illness in lowly silk-spinning moth grubs, were later of great importance in forming ideas as to how microbes might produce disease in man.

Fortunately, microbes are impartial. They attack the devastating insects as well as honey-bees and silk-worms. In the long list of microbial diseases of insects man finds, to his delight, that there are infectious diseases fatal to the agricultural pests: gipsy moths, nun moths, army worms, cut worms, tent caterpillers, ants, locusts or grasshoppers. Even crickets, house flies, the American cockroach and the "elegant grasshopper" of South Africa have their troubles with microbes. Some of the microbes, especially the fungi, stop up the respiratory tubules and choke the insects to death. Others, entering through the intestines or abrasions swarm through the blood of the insects and

kill them with septicemia. A large group of different kinds of bacteria begin their attack upon the intestines of the insects, produce diarrhoea, and the weakness, loss of muscular control and the lack of appetite so devoutly wished for by those who see their crops being devoured by insatiable locusts or grasshoppers.

Bacteriologists have been able to isolate the germs of some of these diseases. In small experiments, and in large scale warfare in this country, Mexico and Argentina, they have been able successfully to combat plagues of gipsy moths, locusts or grasshoppers with an opposing army of microbes. Cultures in broth with a little sticky jelly sprayed on leaves are greedily devoured by the grasshoppers. Under proper conditions, the germs thus spread by man set up an "epidemic" among the insects. Artificially infected insects, liberated among the invading hosts can be used also to spread these diseases. It seems certain, that as knowledge increases, man will make increasing use of bacterial bullets in his warfare against the insect pests.

This sort of bacteriological warfare is, after all, only fighting insects with one of their own weapons. For a long time, long before man suspected that there were such things as microbes, insects have been implanting the germs of disease in human

beings, and in animals and plants. We may say that mentally endowed man is intentionally bombarding insects with germs and that insects are accidental conveyors of disease. However true that may be from a philosophical point of view, the historical fact is that insects were the first to use this sort of poisoned weapon.

The simplest way in which insects carry the germs of disease from man to man, animal to animal or from plant to plant is a mechanical one. They pick up infectious materials on their feet, wings, or bodies and wipe it off on the food or skin of man and animals or upon the leaves of plants. Before the days of automobiles, when garages were stables, the flies bred in manure piles were among man's deadliest foes. They are deadly now wherever they abound. In a short flight from an open privy to the kitchen, they can transport the germs of intestinal diseases from human excrement and wipe them off their feet on food laid out for the human family. Other insects, like the flea, mechanically transport germs of human diseases in their intestines. They suck infected blood from a diseased person and at their next meal, perhaps upon a healthy person, they deposit upon the skin droplets from their posterior ends to make room for the intaken new blood. The germs in these droplets either enter through the wound made

by the insect's bite or are rubbed into the skin when the vexed individual relieves the itch by scratching. The insects are not harmed by these germs of human diseases.

The second method of insect transmission of disease is marvellously complicated. Of the many complex arrangements in nature, the use of different hosts by parasites for different stages of their development is one of the most intricate and amazing. Usually the parasitic microbe goes through a non-sexual stage of multiplication in one living organism, called a "host." When taken into the body of another different sort of host, forms of the parasite with sexual potentialities develop into male and female elements. In this host, the female microbe is fertilized by the male and the progeny of the sexual part of the parasite's cycle of development swarm into other parts of the body of their host. The new microbes of this generation do not wander indiscriminately about the body of the host, but go to the part which will give them most assistance in entering a new host, in whose body they can repeat the non-sexual phase of their lives.

The adaptations of some parasites to hosts are almost perfect from the point of view of the parasite. Usually, one of the hosts is made sick by the microbes developing in his system, while the other

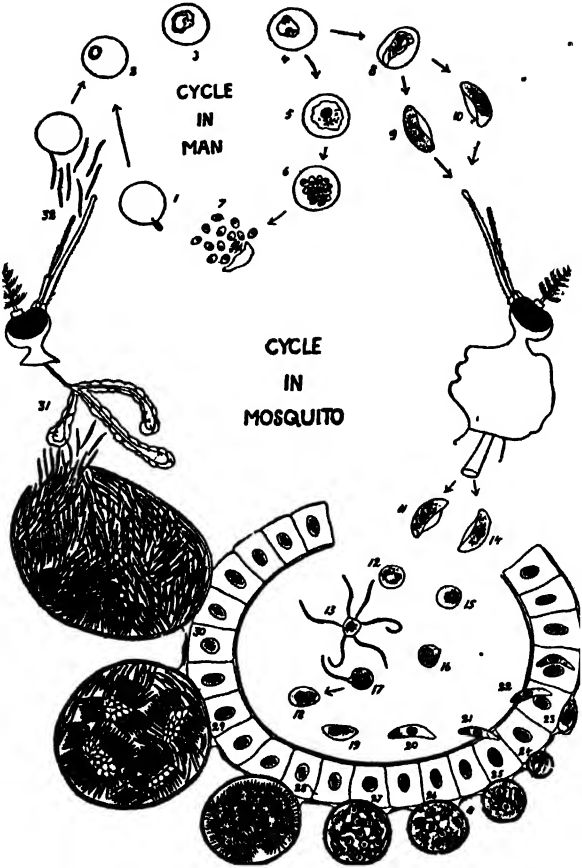

FIG. 13. Diagram of the life cycle of the malarial parasite. The cycle in man is a non-sexual phase of multiplication. The cycle in the mosquito is the sexual phase of development. (From "Protozoology," by C. M. Wenyon, Vol. 2. William Wood and Co., Pub., N. Y., 1926.)

seems to suffer very little from its temporary alliance with the germs of death. Furthermore, the relations established are quite selective. Each parasite has, within narrow limits, especially elected hosts. If, for example, the parasite has adjusted its cycle for man and "dapple winged" mosquitoes, it will not pass through its life stages, but will die, in another animal or another insect, or even another kind of mosquito. The parasites with these two modes of life are usually protozoa. Perhaps some of the viruses may go through similar stages. As yet there is no proof that bacteria use two hosts for their life cycles, though the possibility exists. The importance of all this for man is that he himself, like other animals, serves as host for the non-sexual developmental stages of a number of blood parasites, while insects serve as hosts for the sexual stages of the same microbes. Man and animals sicken and die when they are forced to provide hospitality for these microbes. The flying and crawling insects, on the other hand, go their ways with little disturbance while furnishing a travelling domicile for microbic couples and their families.

The discovery that insects were engaged in this sort of traffic was made in this country within the past fifty years, when Theobald Smith and Kilborne found that ticks were transferring the germs

of Texas fever from cow to cow. Almost at the same time, in India and in Italy, Ross and Grassi were showing that the germ of malaria was being transferred from man to man by mosquitoes. Since then, a number of serious diseases, such as yellow fever, African sleeping sickness, and relapsing fever, have been shown to be spread by mosquitoes, or Tsetse flies or ticks, and other insects. Parasitic microbes have elected also lice, bed-bugs, cone-nosed bugs, sand flies, fleas and almost every insect capable of puncturing the outer casings of man and animals to be their transportation agents.

Some of the most dramatic and heroic stories in man's battle against disease are the accounts of the actions of men engaged in proving that insects carried yellow fever, malaria, typhus fever and other diseases. When Reed, Carroll, Lazear, Agramonte and a group of volunteers tackled the problem of the carriage of yellow fever by the mosquito in Cuba at the beginning of this century, all of them risked their lives, and some of them died from the results of having offered themselves as the subjects of experiments demanded by a rigorous scientific proof. Fine men and keen scientists have lost their lives in experiments with the virus of yellow fever and mosquitoes, in the search to find clues to the mysteries of typhus

fever and lice, and in the so-called "academic" and practical field studies of malaria in swamps infested with microbe-bearing mosquitoes, and in investigations of sleeping sickness in African jungles swarming with deadly Tsetse flies. These men belong to the glorious company of the martyrs of science. Their martyrdom has enriched the human tradition of service to humanity, even at the cost of life. They have rescued whole populations from devastating disease and opened up new lands for the habitation of man.

The control of insect-borne diseases comes down to the control of the insects. Our ancestors suspected this, but did not know it, as they had no microbiologists to follow the dangerous chase of microbes from man to insects and back to man, and then to tell what had been found. In the case of malaria, the ignorance of its true nature is reflected in the name for the disease which relates it to the bad air and miasms of swamps. Ignorance of how to control malaria has no doubt had a great influence upon the course of history. In bringing about the fall of Rome, the penetrating stilettos of the "beaks" of mosquitoes seem to have been every bit as important as the sharp swords of the Goths and Vandals. Civilizations have withered and populations dwindled under the bites of disease-bearing insects, uncontrolled through ignorance of their murderous powers.

On the other hand, the knowledge of the part played by insects in carrying disease has been used by vigorous and intelligent men to wipe pestilences from some of the most plague ridden pest holes of the world. Mosquitoes, bearing yellow fever and malaria, drove the French out of Panama when De Lesseps tried to cut a canal there. Gorgas, however, applying the lessons learned in Cuba, rid Panama of yellow fever and greatly reduced malaria there. His attack was chiefly against the mosquito, using weapons of oil, drainage, and wire netting. He succeeded and his success made it possible to dig the great canal. Malaria is still the curse of tropical and subtropical lands. It is one of the "captains of the men of death." But this ghastly captain, with his hosts of microbes in winged transports will be defeated, with others of his kind, whenever man decides to deflect money from destructive armaments to the betterment of his own surroundings and to apply in vast areas the knowledge and experience he has gained in local triumphs over disease through the control of their insect hosts.

CHAPTER VII

MICROBES AND DISEASES OF ANIMALS TRANSMISSIBLE TO MAN

EVERYONE knows that all animals do not have all the infectious diseases of man and that mankind does not suffer from all the diseases of animals. No one has had to nurse a cow through human typhoid or take care of a human being with bovine Texas fever. No poultry raiser has had to doctor a chicken for foot and mouth disease and no breeder of horses has been bothered by turkey black head in his mares and stallions. Examples such as these are usually explained on a basis of differences of susceptibility between animals.

It is easy to say that differences in susceptibility and resistance to microbes exist. On the other hand, it is extremely difficult to define these terms by showing the conditions underlying them. While a good deal is known about the physical states and chemical compositions of the bodies and fluids of animals, this knowledge is not enough to explain all the differences in their susceptibility or resistance to microbes. Even after some of the

changes brought about by recovery from disease and by immunization are taken into account, unexplained differences remain. Another way of looking at the situation is to keep in view the living nature of microbes. Microbes may be said to have preferences for one kind of animal fluid or another, or for one degree of animal body temperature or another. A microbe may find human tissue more suitable for food than shark flesh, and a germ habituated to the relatively steam-heated quarters of a bird will not thrive in the chilly interior of a frog in a pond. In addition, microbes seem to have special defences opposed to the opposition set up against them by one animal, while lacking protection against the offensive cells of another variety of animal.

Some of the most important secrets for human welfare are locked up in these differences in susceptibility between species, races and even individual animals. The continued exploration of a great unknown territory here is certain to uncover new knowledge, useful to both man and animal and to the general science of biology. Greater knowledge of these conditions will fit man to defend himself more skillfully against the two main ways in which microbes strike at him through the lower animals—the way by which microbes pass from animals to produce disease in man, and th

FIG. 14 The origin of vaccination From a French caricature, showing doctors examining the udder of a cow with cowpox and the "vaccinia" on the hand of the milk-maid (From "Edward Jenner and the Discovery of Smallpox Vaccination," by Louis H Roddis George Banta Publishing Co., Pub., Menasha, Wis., 1930 Courtesy of Wellcome Medical Museum, London, England.)

way by which microbes impoverish man by destroying his valuable beasts.

The special diseases of animals are numerous, interesting and often the cause of great financial loss to those engaged in raising or collecting pets, stock for food, work or hides, for polo-playing, and for circus menageries and zoos. They are a profitable object of study for those who are trying to find out everything about microbes. Since the diseases in this list are not passed on to man, it would be outside the purpose of this chapter to give them more than a mention here. The cases of diseases common to both man and the lower animals are frequent enough to give us much material for consideration. These are so numerous that we cannot take up all of them. A few old and a few new examples should be enough to show that veterinary medicine and human medicine are parts of the same struggle of man against microbes.

Among the older cases of interchange of germs, the story of the milk-maid, the microbe and the mind of Edward Jenner is a good example of what can be done with similar diseases in animals and man. It is the account of the control of small-pox. In England, in the latter part of the 18th. century, when thousands of people died of small-pox and pock marks were more common than freckles among the living, Jenner noticed that milk-maids

who had recovered from a sort of pox, contracted from the udders of cows, escaped the severe human type of the disease. After much hesitation and discussion, Jenner took some material from the cow-pox on the hands of a milk-maid and scratched it into the skin of a boy. The boy developed the mild form of pox we call vaccinia, and two months later, when inoculated with material from a case of human small-pox, he did not contract the disease.

Jenner followed these experiments with numerous observations, and established vaccination against small-pox. Although some of the links in the chain of evidence are lacking, it seems fair to assume here that in the passage from one animal to another, the germ of small-pox, which is one of the mysterious filterable viruses, lost some of its ability to produce disease. Nevertheless, the mild disease it produced left the individual almost as resistant or immune as he would have been if he had recovered from the severe disease. This was a very practical application of shrewd observations about disease.

The knowledge of microbes is not yet sufficient to explain the whole course of events. It has been made clear, however, in many countries and among many kinds of people, that vaccination against small-pox with the virus of cow-pox is the most efficient and safe way to prevent the ravages

of one of the worst scourges of mankind. Wherever vaccination has been enforced by law or practiced universally under the urge of conscience or of fear, small-pox has been reduced to a minimum. Wherever vaccination is practiced spasmodically or neglected, small-pox is common. The United States belongs in the class of delinquent countries in applying this efficient safeguard of public health, as it is lax in vaccination and consequently has too many cases of small-pox.

In these days, the material to make small-pox vaccine is collected from experimentally inoculated animals, chiefly calves. The transmission of other human diseases by this material is almost impossible. Recent experiments seem to promise a supply of even cleaner vaccine virus, grown in cultures. In the old days, dirty medical and lay practice caused catastrophes which gave a bad name to vaccination. In the past, it was sometimes the custom to take the scab from the vaccination sore on one person's arm and put pieces of it into scratches in the skin of other persons. Of course, human diseases, including syphilis, could be and were transferred in this way. Although that sort of convenient but dangerous way of vaccinating was given up years ago, present day opponents of vaccination continue to quote the events of those days as arguments against the

use of vaccine virus. These irrationalities of the faddist are extremely dangerous to the public health, as they hinder the application of useful preventive measures, either by securing restrictive legislation or by providing plausible, but fallacious arguments to lull into inaction the all too lazy public health conscience of our fellow citizens.

Jenner did much more than stop small-pox by spreading a milk-maid's disease. He showed that people could be protected against a severe disease by giving them a mild form of the same sickness. Almost a hundred years later, Pasteur grasped this general principle from the similarity of results he obtained in studying a disease of chickens with those obtained by Jenner with small-pox. Pasteur could immunize his chickens against fatal microbes by giving them doses of the same microbes, somewhat changed or weakened by heat or age. From the experiments on chickens, Pasteur proceeded to experiments upon sheep, at a time when the sheep and cattle industries of France were on the verge of ruin because of the depredations of the germ of anthrax.

Out of respect to the memory of Jenner and the cow, Pasteur named the weakened microbes "vaccines," from the Latin word "vacca," meaning a cow. The word ties up volumes of human medical lore with veterinary medical knowledge.

Since then, any substance used to give man or animals a mild disease or a mild intoxication for the purpose of creating a state of resistance to a severe disease has been called a vaccine. In the course of the years, there has been a lot of misuse of vaccines and a lot of hocus-pocus in the general medical use of these materials. Nevertheless, triumphs have been gained by the use of vaccines against small-pox, typhoid fever, diphtheria, and other diseases. This is a part of man's knowledge of microbes which allows him to fight them with some of their own weapons.

The germ of tuberculosis can feed and multiply and ride around in the bodies of reptiles, fish, fowls, animals and man. It is becoming a fairly skillful parasite of all these hosts and it slays its thousands of them. As the tubercle bacillus of one group of animals is somewhat different from its cousins in other groups of animals, it would be better to call these microbes the germs of tuberculosis. Out of the whole deadly crew, man has most to fear from the tubercle bacilli from cattle, and from his fellow man. In passing back and forth between man and cattle, these microbes retain their individualities. Cattle can be infected with human tubercle bacilli and pass them back to man, and man can be infected with bovine tubercle bacilli which, rarely, he might return to cattle.

The great loss of valuable cattle from tuberculosis is, of course, one forceful reason for man's effort to combat that disease in his herds. His absolutely compelling reason is his need, for the sake of his personal safety, to demolish every lair in which these destructive microbes lurk. The tubercle bacillus can pass from cattle to man in the cattle flesh he eats or in the milk he drinks. The first danger is fairly well prevented by meat inspection at slaughter houses. The second danger is more difficult to avoid. Escape from it depends in part upon the recognition of tuberculosis in a living milk producing cow and in part upon the persuasion or compulsion of people whose livelihood comes from selling milk to give up a source of income for the sake of sparing both babies and adults from taking bottled death when they think they are getting only milk. The recognition of tuberculosis in a live cow may be easy when the cow is in the last stages of consumption. But when the tuberculous cow is apparently well or only slightly ailing, the diagnosis is as difficult as the diagnosis of early tuberculosis in human beings. Sometimes the germs may be found in milk examined by the bacteriologist. At other times, the tuberculous cow, a potential source of danger, may not be shedding any microbes in the samples taken for examination.

In these cases, the so-called tuberculin test is helpful. Tuberculin is a product of a culture of the germ. Animals, including man, suffering with even mild forms of tuberculosis are very sensitive to this substance. When it is injected into the skin, under the skin or dropped into the eye of a tuberculous animal, a more or less severe reaction takes place, with redness and swelling at the point where the tuberculin was applied, and a general reaction indicated by fever. As normal animals do not give a tuberculin reaction, the test is helpful in making a diagnosis. The trouble with it is that some animals apparently in the pink of condition will also have pink and red and swollen tuberculin tests. Usually, after such an animal has been killed carefully made dissections will show the small tuberculous focus. Sometimes no focus is found. In spite of the troubles for the individual farmer which have come from the use of this test, its general application has been an efficient aid in eradicating tuberculosis from herds.

The killing of all the "reactors" may seem to be aiding the microbe in bringing about the death of the animals. Its final effect, however, is to kill off the microbes by removing their breeding places. After that has been done, all efforts are toward keeping the doors closed against reëntrance of new germs, by not admitting "reactors" to the

healthy herd. With respect to the second part, in avoidance of the danger of transference of tubercle bacilli from cattle to man through milk, man has learned from sad experience that he cannot depend altogether upon persuasion and coercion to prevent his neighbor selling him a glass of milk with a death sentence concealed in it.

There has been a great improvement in the good sense and conscience of the dairyman in this field of sanitation. Nevertheless, ignorance, laxity and disregard of general human safety by men engaged in making a living from milk, as in some other pursuits of money in lines touching human welfare, must be met and defeated. The chief means of doing this is to regard all milk with suspicion and to require that it be heated hot enough to kill tubercle bacilli, as well as other germs, before it is sold for human consumption. This is effected by voluntary and by required pasteurization of milk.

In these days, we may be witnessing the spread of a disease from animals to man. Increased sharpness of diagnosis, increased alertness to the danger and increase in the spread of knowledge may be causing the discovery of so many new cases of undulant fever all over the world that it is really somewhat difficult to be certain the disease is actually spreading. It is certain, however, that

the passage of the germ of undulant fever back and forth between animals and man is creating an important modern problem of human sickness.

Undulant fever is an ancient disease. The beginnings of the modern understanding of it were made at different times and in two widely separated countries. In the 'eighties, Bruce found that the soldiers in the garrison on the Island of Malta in the Mediterranean were suffering from a fever contracted by drinking a minute microbe in goats' milk. In the 'nineties, in Denmark, Bang found that infectious abortion of cows was caused by a microbe. Perhaps because Bruce called his organism by one name while Bang called his by another name, no one during nearly thirty years suspected that these two were very much alike. Finally Alice Evans, at the Hygienic Laboratory in this country, and other workers here and abroad, demonstrated that the Malta fever microbes of Bruce and Bang's microbe of infectious abortion of cows were so closely alike that they could be told apart only by the most refined tests. At the time when this synthesis of knowledge was being made by Miss Evans, cases of a disease like Malta fever were traced to cow's milk containing the microbe of infectious abortion.

Since then, it has been clearly shown that Malta fever, now more generally called undulant fever,

was occurring in all sorts of places outside the Island of Malta, and that the germs producing the disease were coming to man directly through his contact with diseased cattle and swine or indirectly through cow's milk. The clue followed by the detectives working on the unravelling of this mystery is the microbe. The conditions have been uncovered by tracking the microbe, and the measures for control are being based on ability to track down these germs. The removal of infected animals from herds is benefitting both human beings and cattle, and the pasteurization of milk is proving to be a safeguarding barrier between man and another approach by microbes.

Dogs have contributed their share to the gain in knowledge of microbes, which has benefitted both dogs and their masters. The intimate association of man and dog, from vigorous participation in a hunt to coöperative sheep-herding of a flock, from a normal and entertaining friendship to maudlin, sentimental pampering, from sharing the same house to sleeping in the same bed, would be the source of considerable harm to both man and dog if they were susceptible to many of the same diseases. Fortunately, these animals which contribute so much good to each other, have very few disease-producing germs to exchange. Of these, the chief from our point of view, is the filterable virus cause of rabies.

FIG. 15. Pasteur in his laboratory. This shows Pasteur inspecting a spinal cord preparatory to its use in making rabies vaccine.

Since a human being with rabies, parched with thirst, has excruciating spasms of his throat when he tries to drink or even at the sight and thought of water, man has called the disease hydrophobia. Hydrophobia is only one symptom produced by the virus disturbing many parts of the nervous system. In dogs, the appetite is perverted and the animal chews up sticks and bits of inedible wastes. Some rabid dogs sink into a dumb paralysis. The furious dog wanders about or runs aimlessly, evidently under great excitement and anxiety, biting at anything in his way. When he bites another animal the virus in his saliva enters the wound made by the teeth. From this wound, the microbe proceeds along nerves to the central nervous system, and from that seat brings on the dreadful symptoms and fatal ending of furious or dumb and paralytic rabies. All sorts of warm blooded animals, man, cattle, swine, dogs and wolves are so susceptible to rabies that it is still further fortunate that the only way the virus has of passing from one animal to another is through a wound, usually the puncture wound of a bite.

In the latter years of his life, Pasteur was drawn by sympathy for mankind and interest in a great mystery to undertake the study of hydrophobia. Neither he nor anyone since has ever seen the cause

of this disease, but thanks to Pasteur something has been done to lessen its effects in man and perhaps to decrease its prevalence in dogs. Pasteur devised a vaccine for rabies, made of virus in different degrees of potency in the partially dried spinal cords of rabbits inoculated with the microbe. The incubation period in rabies, the time elapsing between the introduction of the virus and the appearance of the first symptoms is often long, lasting from several weeks to several months. This gives time for immunization and Pasteur furnished the vaccine to be used during this interval.

Although the Pasteur treatment is not an infallible prevention of rabies and although some accidents have occurred from its use, in hundreds of thousands of cases it has justified the great master's belief in it. In honoring this achievement of Pasteur, the grateful people of France built the Pasteur Institute in Paris, which has been one of man's forts and bases of operations in his world-wide application of many discoveries made by Pasteur to combat disease. The countries most successful in keeping down the number of mad dogs and therefore having the fewest cases of human rabies have been guided by men who have not let sentimentality warp their intelligence in the handling of so obvious a chain of events as occurs

in rabies. The control of rabies unavoidably involves quarantine and muzzling of dogs. These methods serve to exclude rabid dogs and prevent dog bites, and in a modern urban community there would not be any rabies unless there were dog bites.

The degree of common sharing of microbes by man and animals is barely indicated by these comments on the causes of tuberculosis, small-pox, cow-pox, undulant fever, Malta fever, infectious abortion and rabies. A partial list of diseases transferred from animals to man would include glanders from horses, spirochetal jaundice, rat-bite fever and plague from rats, tularaemia from rabbits, anthrax from sheep and cattle, psittacosis from parrots, foot and mouth disease from cattle, a form of erysipelas from swine, lockjaw, botulism and gas gangrene from various animals. There are others, but it would be best to close the list before this book becomes a medical dictionary. The names of the diseases are numerous and imposing. Yet they give only a hint of what microbes do to man through animals. Indeed, microbes, more crafty than the Greeks at Troy, steal into the citadel of human health, not only in the body of a horse, but also in the bodies of nearly all the animals.

CHAPTER VIII

MICROBES AND DISEASES OF MAN

THE life of man, as Pasteur said, is an equilibrium constantly menaced by microbes. From the time of his coming into the world until the time when his earthly substance has been returned in molecular fragments to the everlasting cycle of the elements, man's body is the home of myriads of bacteria, protozoa, fungi and viruses—and of even larger parasites and minute associates, which we decided to leave out of the class of microbes.

Many of the microbes from the air, soil and water get into and upon the human body, and do no harm. Other microbic messmates of man, especially those in his intestines usually do him no injury and may be beneficial at times. A few, out of the many species of microbes, produce disease. Their damage to man's chief object of interest—himself—makes these microbes seem to outrank in importance all the other germs. They are, in fact, so immensely influential that they fully justify the statement of Morris, quoted by Kopeloff in his book on "Man Versus Microbes," that "a man is only what his microbes make him."

It should not be overlooked, however, that modern man is not a passive sufferer from the depredations of microbes. His body is a frail animal mechanism, susceptible to the attacks of germs. His intelligence, on the other hand, has discovered the invisible enemies of his body and has devised ways of aiding the natural powers of defense against germs and means for bringing other forces to bear against them. Since the devastating effects of microbes upon human beings are too great to be dealt with in detail here and since so many aspects of microbial activity and infection have been described in other sections of this book, it seems best to take up in this chapter the more general sides of man's personal relationship to microbes, and to tell something about the pathways of infection, the public health applications of the knowledge of microbes, and the uses of the processes of immunity.

Each group of the parasites which produce disease has fairly well defined ways of entering and leaving the human body. In order to perpetuate its species, each kind of parasite must pay attention to its entrances and exits. If we look at diseases from the point of view of the parasite, we see at once that the killing of man by a microbe is really an evidence of lack of skill on the part of a germ whose main object is to secure a comfort-

able billet with a good supply of food in the body of a man for as long a time as possible. The bungling germs, new to the parasitic graft, are the ones which usually destroy their hosts quickest. When they do that, they have before them all the difficulties of finding a new host to give them food and warmth and shelter.

The more skillful parasites, like the germs of tuberculosis and syphilis, enter stealthily, sometimes without leaving a trace of disturbance at the point of entrance, and live and multiply for a long time in the body of their human host, producing a minimum of destruction or at least slowly destructive processes which may ultimately break down a great deal of the tissue of the host. These parasites enter in special ways and leave the body by way of these broken down parts of the body of the host. Man's knowledge of the pathways of entrance and exits of parasites helps him check the spread of microbic agents of disease.

The entrances into the body are called, picturesquely, "portals of entry." The skin and mucous membranes, the respiratory tract, the gastro-intestinal tract, and the gentio-urinary tract are the portals of entry for germs into the human body, as each of these communicates with the outside. In general, there are special groups of parasites which have become adapted to entrance

into the human body through these different portals.

A large group of spherical bacteria called cocci, some of the fungi, and a few spirochetes and protozoa enter the body through the skin. Some cocci, entering through the skin, produce the boils and carbuncles from which man has suffered from times even before the lament of Job, others cause erysipelas and various inflammations of the skin and underlying tissue. The bacteria of plague, tularaemia and tuberculosis can enter in the same way. Fungi, from the types producing so-called "athletes foot" among the devotees of sport and the common ringworm of the less active, less stylish and more sedentary members of the human community to the yeast and mold-like organisms of severe destructive diseases enter usually through the skin.

The mucous membranes of the nose and throat are the common portals of entry of the germs of diphtheria, scarlet fever, and meningitis. In one sense these membranes form a part of the passages of breathing and hence these diseases come about chiefly through the inhalation of their microbes. Probably measles, small-pox, infantile paralysis, all of which may be due to viruses, come into the body with the indrawn breath which takes in not only air but dust and germ laden droplets

of secretions from diseased human beings. The group of parasites which have a more obvious portal of entry through the respiratory tract are those which cause diseases of the lungs, namely, the germs of pneumonia, influenza, whooping-cough and tuberculosis.

Man drinks and eats a good deal more than is good for him, and he does this at times when he is unaware of the dangerous germs lurking in his food and water. When he swallows the parasites which have specialized in entering his system by way of his intestines, he risks a grave disturbance. These "sewer rats" among the microbes are chiefly the germs of typhoid fever, dysentery and cholera. They set up their breeding ground in the intestine, tear it more or less to pieces, and poison the whole system. The genito-urinary tract is the usual portal of entry for the microbes of syphilis and gonorrhea, but may admit many of the other germs which are able to maintain themselves on mucous membranes.

Nothing in life is simple, not even the behavior of the simplest forms of life. Therefore it is not astonishing to find exceptions to the usually regular modes of entrance of parasites into human bodies. The germs of gonorrhoea can enter a baby's eyes, while it is being born and produce blindness, unless checked by the instillation of

silver nitrate. The innocent game of "pillow kiss" has been the means of implanting the microbe of syphilis on the cheeks of girls from contact with one who had this spirochete in his mouth. The germ of tuberculosis swallowed in milk may begin its fatal march from the wall of the intestine. A further disorder in this idealized scheme of parasitic behavior is produced by the forcible implantation of a microbe into the body through a puncture wound. The virus of hydrophobia, the germ of lockjaw and the germs of gas gangrene usually require the assistance of a penetrating foreign body to get within the tissues of a human being.

In spite of these exceptions, the knowledge of portals of entry is reliable and can be used by man as a basis for his rational measures of public health, hygiene and personal protection. To guard against typhoid fever, he has taken care to purify his water supplies, exclude typhoid carriers from his food handlers, pasteurize his milk, "swat" his flies, cover up his excrement, decompose his sewage, and handle his fellow being with typhoid fever with precautions. Man's primary object here is to prevent himself from eating the germs of typhoid fever, as he knows that these microbes attack him through his intestines.

It must be confessed that although most human beings know enough about these means of prevent-

ing typhoid fever, many of them are often too lazy, too slovenly, too careless, too economical, too political or too selfish to apply them. By these means, the once dreaded cholera has been excluded from this country and, although much remains to be done, much has been *accomplished in diminishing* typhoid fever and dysentery by denying the microbes their elective portal of entry. Venereal diseases could be controlled in the same way, if infected individuals could be prevented or would prevent themselves from aiding the microbes of syphilis and gonorrhoea in reaching their chosen portals of entry. But this is a more complicated problem, tied up with individual human behavior and extremely difficult to handle according to the generalized schemes of sanitation which have been applied to the diseases borne by food and water.

It is urgent, however, that human beings be frankly informed of the wideness of the spread of venereal infection among them, both for the preservation of the individual's health and the stamina of the race.

The microbes which enter by the respiratory tract present one of the most acute problems of modern public health. In these days, these microbes are the germs of world-wide pestilences, like the epidemics of influenza and probably infantile paralysis, and the severe, though more

local outbreaks of the common cold, measles, pneumonia, scarlet fever and the ever-present "great white plague," tuberculosis. The air is common to all men and many men breathe the same air. Under modern conditions, it is easy for the germs which enter through the respiratory tract to find a short path from the lungs of one man to another.

During some epidemics in the past, the doctors went about the town hooded and masked, with beak-like extensions over their noses, in which they burned spices or sulphur. No one would be admitted to a subway car or movie-house in such a fuming garb nowadays, and aside from those closely attending the sick, no one wears a mask to sift out the germs from the air. Besides, it is difficult to say how much good such a get-up would do, except to keep a man from coughing and sneezing in his neighbor's face. It must be admitted that, while man knows a good deal about the entrance of microbes through the respiratory portal of entry, he knows relatively little of practical value about the means of preventing the diseases admitted through this doorway.

Most of these microbes which pester man are fairly regular in their ways of leaving his body and the ways of exit are often the same as those of entrance. Those which enter by the skin often leave

the body from sores on the skin. Those which enter by the lungs usually leave by the secretions coughed up, expectorated, sneezed out and generally blown about by the diseased individual. The microbes of the intestinal tract usually depart in the excrement. Knowing these things, man knows where to apply his energies to prevent the transfer of microbes or to kill them. By curing the open sores of syphilitic, gonorrhoeal, and tuberculous individuals and of other persons with other external infections, he can put a block in the passage ways of germs from man to man. By destroying infectious secretions, by disinfecting excreta, and by personal hygiene, he can recapture and annihilate some of the disease-producing germs which have escaped from his body.

To deal with the parasites which reach their portal of entry into man by dodging about in the bodies of other animals, man has only to apply the knowledge he has gained from the study of the behavior of these microbes. He strikes at them through their lower animal hosts, slaughtering infected animals or protecting them against infection, destroying at their breeding places or in their adult stages, the insects which serve parasites in the proliferative stages following their sexual phases of development, or screening himself against the bites of infected insects. In all these

situations, man's fore-knowledge of the ways of attacks of microbes shows him how to parry their thrusts.

If he lived up to all he knows, man would live a longer and healthier life. In spite of his failure to do all he might do for the sake of his health, he is equipped with knowledge and need not waste his efforts, even during periods of fear and excitement, in the misdirected attempts which characterized the opposition of our superstitious ancestors against the attacks of microbes.

Some families of microbes colonize the crevices and surfaces of the body without doing any harm. But after the disease-producing germs have gained entrance to the body of a human being they show that they have a number of damaging capacities. Wherever they grow, they injure the cells of the tissues. Very little of this injury seems to come from pressure produced by a crowd of microbes in one small place. Most of the damage is produced by poisons elaborated or liberated by the germs. Some of these poisons act locally, others, called soluble toxins, are carried by the blood stream to other parts of the body and have a tremendous effect upon other tissues and organs. Until these toxins were discovered, no one could explain how the germ of lockjaw growing in a barely perceptible wound could cause spasms

and nervous disturbances by deranging a central nervous system in which the germ itself was never found. The diphtheria bacillus is a microbe which, from its seat in the tonsils, produces disorders of the heart and paralysis of muscles by means of a diffusible powerful poison. The true bacterial toxins are almost unbelievably potent, and once they became attached to the cells for which they have special affinity nothing can dislodge them.

Fortunately many of these disease-producing germs grow only where they are implanted in the body. Unfortunately, quite a number of them are able to invade the blood stream, produce septicemia, multiply in the circulating blood and become reimplanted in places distant from their point of entrance. At those distant new depots, perhaps upon the valves of the heart, perhaps in the brain or kidneys, microbes of these types set up new colonies of their progeny and increase the seats of infection.

Even the unconscious cells of the body do not remain passive under these microbial blows. In the first place, these cells have integrities of structure, or special secretions, like the acid gastric juice, which oppose a primary barrier against the invading germs. If the barrier is broken down, two other weapons of defense are brought to bear by the body upon the hostile germs. The first of

these is the mobilization and engagement in combat of the white corpuscles of the blood and tissues. Because these cells can gobble up and digest microbes, they have been called phagocytes. They swarm around and into the infected areas and engulf thousands of the germs. They do this if they can. Some germs are capable of warding off these microbially omnivorous cells, and in that case the germ is apt to get the better of the situation.

The next line of resistance of the body is a defense against the chemical warfare of the microbes. Certain substances in the blood and tissues are capable of neutralizing and rendering harmless the poisons produced by the germs. In a normal man, these chemical defenses are apt to be feeble. In a man who has recovered from the attacks of some microbes, or who has had a slow and mild disease, these chemical defenses are usually powerful enough to help save his life. In the jargon of the science of immunology, these substances are called "antibodies," because they have an anti-action opposed either to the microbes themselves or their poisons. Antibodies can help phagocytes by making the microbes more "palatable" and more easily engulfed; they can help to remove bacteria by causing them to stick together; they can dissolve germs and they can

neutralize toxins. The defenses of the body are therefore partly cellular and partly humoral, using the ancient term of "humors" for the fluids of the blood and tissues.

In the last chapter, we saw how the observation of the immunity to small-pox of cow-pox infected milk-maids led to the use of artificially produced mild infections to protect people against severe diseases. Later it was found out that somewhat similar protective states of resistance to infection could be brought about by injecting either dead microbes or their poisonous products under the skins of susceptible individuals. On these observations, the practice of artificial immunization by the use of vaccines has been built up. Vaccines are sometimes good things to use to gain protection in advance of infection, chiefly protection against small-pox, typhoid fever, diphtheria and possibly scarlet fever. While many vaccines have been a lucrative source of income to physicians and medicine-houses, many have been a disappointment to those who received them. The efficient vaccines are triumphant demonstrations of the artificial production of active immunity.

When microbiologists tried to find out what effect the blood serum of these actively immunized people and of people who have recovered from disease would have upon microbes, they discovered the

antibodies and many additional useful things. An important fact, discovered about forty years ago, was that the blood serum of an immune animal or man, after vaccination, after injections of toxins, or after recovery from certain infections had the power to protect a normal animal against microbes if the serum were injected under the skin, into the muscles or into a vein. Unfortunately, it had no effect if taken by mouth, as the digestive juices destroyed its protective power.

The necessity of injections of vaccines and serums certainly started the era of hypodermic medication and led us into this age of the sharp hollow needle and syringe. By experiments on animals and in the treatment of human beings, the old remark of Van Helmont became a modern truth, that the blood of one who has recovered from certain diseases has a "balsamical" and protective quality which can be imparted to a recipient of that blood or its cell-free serum. The practice of conferring immunity upon man or animal by injecting the serum from an immune man or animal is called passive immunization. In active immunization, the diseased, poisoned or vaccinated animal builds up its own defense. In passive immunization, the animal injected with serum benefits without effort from the labors of the original sufferer. Like many benefits easily gained,

passively acquired immunity is transient. It gives a quick and temporary benefit.

The rapidity of the protective action of a serum is very useful in the treatment of some diseases. The best example of the value of rapidly acquired passive immunization is the treatment of diphtheria with antitoxin. Antitoxin against the poison of the germ of tetanus has its place in the prevention and treatment of lockjaw. Serums useful against meningitis and pneumonia are available. Antitoxins against poisons of the germs of botulism and gas gangrene have been used with occasional benefit. Nevertheless, absolute dependence cannot be placed on antibacterial serums, antitoxins or on the blood of those who have recovered from a number of diseases. There is still much work to be done to improve these and other methods of treating infections. The failures emphasize again the value of prevention.

An extraordinary property of these serums containing antibodies is their specificity. They usually react almost exclusively with the microbes or toxins which caused their production. Diphtheria antitoxin has no effect on tetanus toxin, and the serum antidote to lockjaw poison has no effect upon diphtheria toxin. The serum which dissolves or sticks together typhoid germs has no effect upon the germs of pneumonia, or even upon

germs more closely related to the microbe of typhoid. It is logical, therefore, to use these antibodies as detective reagents. With them a microbiologist can pick out and can almost identify one kind of microbe from a crowd of similar ones. If he has a known germ to work with he can tag his unknown serums by observing their special reactions and if he has a known antiserum he can use it to label unknown germs. The diagnostic laboratories use these tests to aid physicians to diagnose disease. They help him to spot syphilis in patients with obscure symptoms by examinations of the patients' bloods and they help to confirm or change the doctor's opinions in a great group of fevers and other maladies.

This science of serology, which grew out of the study of microbes, is now much wider than its original field. By means of it, all animals, as well as germs can be grouped in classes. It discovers the blood relationships of man to apes, tracks down human murderers by the blood stains on their clothes, serves to safeguard transfusions of blood and helps to settle questions of disputed paternity. The science of microbes has drawn upon every other source of scientific knowledge. It has also contributed its share of knowledge to the other sciences.

Chemical warfare was used by man against

microbes long before he used it against himself. From the beginning of his knowledge of germs, he has experimented with ways of killing them with chemicals. Under the name of disinfectants, he has tried out almost every conceivable combination of chemical compounds and mixtures and squandered fortunes upon the attempt to put some sort of poisonous salt upon the tail of an elusive germ. Fundamentally, the search for efficient germ killing disinfectants is a rational procedure. The mixing of carbolic acid, bichloride of mercury and other poisonous compounds with dead materials containing microbes will usually kill the germs. But the absurd lengths to which these procedures of spraying and washing with disinfectants and fumigation with poisonous vapors were carried, bring tears to the eyes of modern sanitary officers who yearn for the money wasted on disinfectants to apply to better purposes. Often disinfecting materials had such strong smells that the human user of them thought that the virtue of the compounds was commensurate with its odor, when really they had far less effect than soap and water or sunlight and air.

The real problem confronting man is the problem of disinfecting his body. This is extremely difficult. The substance of microbes is so much like that of man, that it is hard to poison a microbe

in a man without poisoning the man himself. Many disinfectants that are active and efficient in killing bacteria in test tubes, are ineffective in the human body, either because they cannot be applied in the body in sufficient concentration or because they combine with body cells or body fluids before they can reach the bacteria, or because the body changes them into inert chemicals. The names of all the vaunted disinfectants which have been recommended for human use would fill a chemical dictionary. Old compounds, with a moderately good disinfecting action are continually being mixed with new flavors or new combinations of odoriferous substances and sold through high powered advertising to physicians and to the general public as cures for one disease or another, as tooth pastes, mouth washes, and as chemical defenses against everything from common colds to venereal diseases.

From all this welter of patent medicine disinfection, it is certain that substances will emerge with their capacities well established by careful tests upon microbes in tubes and in experimental infections and with experimental data supported by sound clinical observations.

By the hands of skillful chemists and well trained observers of microbes, a few compounds capable of killing microbes inside of man have been

sorted out. The stirring example of this sort of research is the discovery of "606" or salvarsan, made by Ehrlich when he was searching for a cure for syphilis. Salvarsan has been likened to a "poisoned arrow." One part of the compound, like a shaft, carries a point of the poison arsenic into the body of the spirochetal microbe. It is a marvellous drug, but not always the rapid and completely germ destroying substance its early users thought it was. It stands, however, as a type of compound on which man can base a definite hope of gaining chemical weapons against his microbic foes. A science of chemotherapy is developing on the basis of studies of arsenicals in syphilis, quinine in malaria, and emetine in amebic dysentery, which offers promises of great relief from the destructive activities of microbes embedded in the flesh of man.

CHAPTER IX

MICROBES AND CIVILIZATION

THE evidence presented in the foregoing chapters, while far from being complete, indicates that there is little or no exaggeration in the statement, that microbes are the masters of man.

It has been shown that man is dependent upon some of them not only for the best varieties of his daily bread but also for many of the elemental food-stuffs. Man's life is constantly menaced and often destroyed by microbes. Man cannot get along without microbes and is often unable to get along with them. In the chapters on the agricultural and industrial uses of microbes and in those on the relationship of germs to disease, it was shown that man, in turn, has gained some degree of mastery over these microbes. This mastery, however, extends only to provision of favorable conditions for the growth and activities of a few captured races of germs and to the prevention or mitigation of the effects of others upon his body. His authority does not extend over the teeming myriads of this invisible population.

Since the intimacy of man with microbes has been continuous throughout the course of human history, it has profoundly affected the whole behavior and development of man. In this final chapter, it will be appropriate to consider some of the general aspects of the relationship of microbes to man, to see how microbes have influenced the customs, habits, philosophy, religion and mode of life of man.

Ideas about the nature of disease have always been a part of man's philosophy and religion. Among the diseases which have influenced his point of view, the most important have been the infectious diseases, those due to microbes. When man was ignorant of the actual causes of these diseases, it was natural for him to explain their mysterious appearances among men in terms of his conceptions of other invisible forces influencing his life. When the soldiers of ancient Greece sickened in their camps, they imagined that a displeased and peevish Apollo was shooting invisible arrows of disease into their bodies. One of the ghastly four horsemen of the Apocalypse was a visualization of Pestilence, riding down from the inscrutable heavens to scourge a sinful population. Later on, subtle miasms and "influences" seeping out of the earth were supposed to be the spreaders of disease.

These superstitions determined the activities of people. People attempted to appease the raging gods with sacrifices. Under the lashing eloquence of a prophet or preacher, who saw in pestilence an expression of divine wrath against some human behavior which the preacher thought improper, individuals and communities of men became penitent, and made efforts to reform their ways. They lived in fear of the supernatural elements in disease. They lived also in a filth which they did not realize contained more than dirt. Often, when they attempted to build up cities and countries, all their efforts were undone by the unseen microbes, as the superstitions of the men of those times did much to make conditions favorable for the spread of disease. The ravages of the black death, the sweating sickness, typhus fever and malaria undermined the social and economic structures, limited commerce and gave the mass of mankind a sense of helplessness commensurate with their miseries.

The discovery of microbes uncovered the previously invisible causes of disease. It robbed disease of its immediate supernatural quality. The microbes themselves, like all living things, are still a part of the ultimate mystery of this universe. But since man knows something about them, their mysteriousness is not at all as sinister

as it was. In place of the pitiful, self-destructive, and irrational practices which ignorant and superstitious man used in the face of disease, he now behaves according to a rational plan. Some of the medical and sanitary practices of these days will, no doubt, seem absurd to our descendants.

But the main thing here is the point of view created in man by his appreciation of the physical reality of the microbes. He still has a natural fear of disease and still acts in hysterical and misdirected ways under the threat of the pestilences which he cannot yet control. Even under affliction from infectious diseases of more or less unknown causes, man is nowadays conscious of opposing another living thing, a microbe, not an immaterial arrow of a god, not a ghostly horseman and not a poisonous wraith. During the course of man's adjustment to the universe he lives in, every science has contributed something to the independence of his thought. It seems fair to say, however, that microbiology has been one of the most liberating of these influences, because in removing the fear of the supernatural in disease it removed a superstitious dread from daily life. The study of microbes has shown man how he, by his own rational efforts, can control at least a part of his destiny.

While the infectious diseases of individuals have

had their influence upon these states of mind and behavior, the diseases of groups and communities of men have had a much more far-reaching effect. A few scattered cases of fever, cough and pain might be regarded as curiosities. When, however, thousands of men are attacked within a short time by this same fever, cough and pain, and when, as a consequence, thousands die, the disease assumes a vast and imposing quality. It becomes an epidemic, a dread something settling down upon the whole people.

Under the stress of epidemics in the past, communities of men have been stripped of the restraints of culture and comforts of accumulated wealth and have sunk through libertinism, unbridled criminality or religious fervor into dumb and savage barbarism. Out of these experiences, man learned that his neighbor could be a dangerous carrier of the unseen evil. He learned that these diseases were contagious, transferred by contact between individuals. The word contagion is too narrow a term, as these diseases may be spread indirectly as well as by direct contact. Hence the better term for them is communicable diseases. Many of the communicable diseases, such as scarlet fever, infantile paralysis and others have epidemic episodes.

From ancient times, the mysteries of the rises

and declines of epidemics have engaged the thought of biologists, and medical men, as well as philosophers and theologists. Even in these days, these mysteries are not explained. It is known that two sets of living things are concerned in epidemics. One is the human being and the other is the microbe. One way of explaining epidemics is to suppose that great numbers of human beings at one time have an unusual susceptibility to some microbe, like the germ of influenza, and provide a huge mass of inflammable tinder which is set on fire, as it were, by the germs, to be consumed in one great conflagration of infection. Both laboratory experiments and some natural experiments give support to this conception.

Experimental epidemics can be set up in villages of mice in a laboratory, and it has been noted that when representatives of a "superior civilization" have landed in remote parts of the world, as in the South Sea Islands, the natives have died by thousands in epidemics from microbes introduced to them by their supposedly uplifting visitors. These previously healthy natives, unaccustomed to some of the microbes to which civilized man has become habituated, have succumbed by thousands to the attacks of germs against which neither the cells of their bodies nor the cells of their brains gave them any means of

defense. Measles and tuberculosis have spread like wild-fire among some unprotected islanders, producing fatal epidemics among the insular aborigines, while they would produce limited outbreaks among the inhabitants of a continental city.

Another way of explaining epidemics is to suppose that the microbial causes suddenly gain an increased ability to produce disease. There is evidence of ups and downs in this virulent potency of germs, but it is not enough to explain the whole effect. Epidemic rise and fall, and the peculiar cyclic periods of disease are still so mysterious, that even modern physicians are reviving an ancient indefinite notion of "epidemic constitution" to account for them. The problem, however, is being attacked, not with prayers and incantations, but by experiment, which is the great way of salvation here.

The experimental method is the basis of a great part of modern thought. Our cities, our commerce, our food supplies, our use of raw materials, our educational system, our government, our public health and sanitation and our medical practice are largely the products of the application of the experimental method. Unfortunately, it is not as extensively applied as it might be. If it were more generally applied, most quackery in all these fields

would not have a chance to reap the profit gathered today from the gullible. The essence of this method is to deny any special sanction to authority. By this method, observations or experiments are made, conclusions drawn and then the conclusions are subjected to other experiments to test their validity.

In the realm of physical and natural phenomena, at least, if a doctrine cannot be substantiated by demonstrable facts, the modern man should not be and usually is not convinced against his senses and observations by any awe of enthroned authority. Modern physics, relativity and the studies of how man knows anything at all about the apparently external universe, have introduced a great deal of confusion and fundamental upheaval. Nevertheless, the experimental method still holds its power as a sound and rational way for man to try to find out something about the things that take place in the world. This method has guided man out of dark superstitions about disease into his present clear inspection of their causes.

Following rules condensed by Robert Koch, the investigation into the cause of a disease follows a definite logical course. In order to be able to say that a microbe is a cause of a disease, the microbe must be found in the diseased parts, sores or other lesions. Next the microbiologist must obtain a

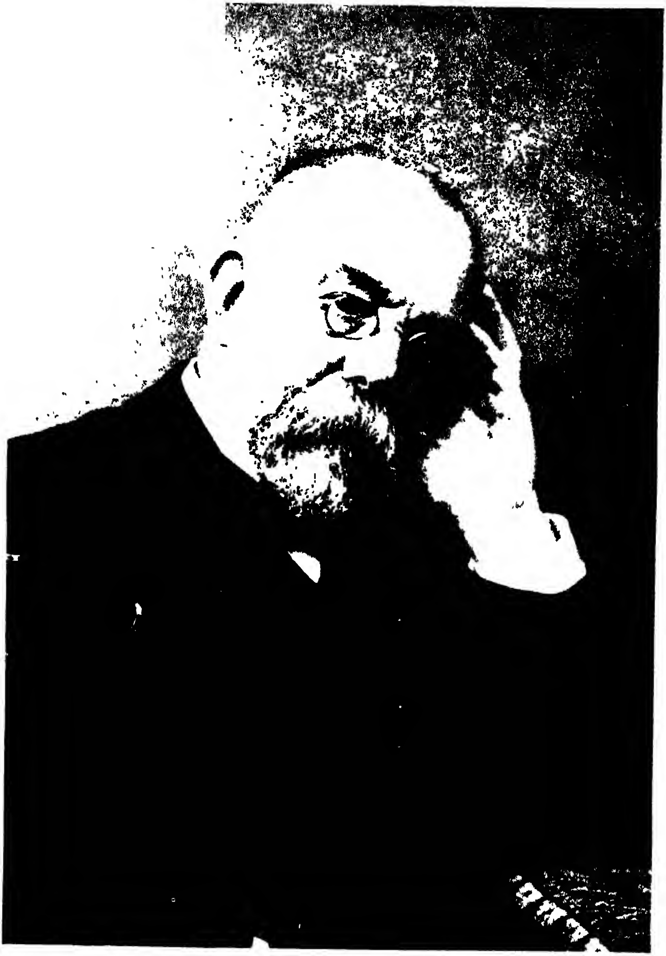

FIG. 16. Portrait of Robert Koch. (From "Bacteriology," by H. W. Conn and H. J. Conn, Williams and Wilkins Co., Pub., Baltimore, 1926.)

pure culture of the microbe, uncontaminated by any other germ. With this culture of the microbe, he should be able to reproduce the disease by some form of experimental inoculation, and, finally, recover the same microbe again from the experimentally produced disease. The argument becomes clinched when a rigid proof of this sort is obtained. Furthermore, the facts are recorded in detail so that anyone with sufficient skill, patience and materials should be able to reproduce the entire sequence.

It must be admitted that all of these stages of the proof have not been brought forward in every case. Some microbes cannot be cultivated outside the human body, and some diseases cannot be produced in any other animal than man. Nevertheless, this microbiological application of the experimental method is responsible for our present conceptions of the causes of disease, and hence, through the study of microbes, the experimental method must in greater or less degree, enter into the consciousness of every man, for no man is exempt from microbes.

Man's approach to microbes through the experimental procedure is profoundly influencing man's relation to his fellow man. The care of the sick of his own kind is a shining example of the alteration in his behavior. In these days, a leper is

rarely stoned to death by men carried away by unspeakable terror. The leper is isolated in comfort in a place from which his microbes cannot spread to other men. Modern aspetic surgery, with all its life saving blessings and its capacity to remake a damaged human body, is based upon man's knowledge of how to exclude disease-producing germs from wounds of operation or how to reduce their harm in infected wounds.

Experimental knowledge of microbes has greatly increased the safety of child-bearing and given scope to the modern growth of conscientious care of a woman in all the stages of her pregnancy. The vast influence of public health and sanitation, with both legally and unofficially recognized sanctions, is regulating the ways in which people live together in homes, in office buildings, in cities and in territory as widely extended as the whole world. Examples can be drawn from almost every activity of human life to demonstrate the influence which the knowledge of microbes is having upon man's humanity to man, and the direful consequences which follow his ignorance or neglect of the influences which microbes can exert upon his life.

Microbiology is obviously a conspicuous strand in the web of modern life. What the fabric may turn out to be at the end of the weaving is diffi-

cult to say. By applying his knowledge of microbes man is interfering with a very pervasive natural process. Modern man is what he is partly because he is descended from ancestors who survived, without the aid of science, the destructive attacks of microbes. In these days, the knowledge of microbes allows man to protect susceptibles against these germs and to populate cities and great districts with people who have been spared from the attacks of microbes which might have destroyed them.

In the past, microbes have been a part of the forces of nature which selected the kinds of men who lived in the world, just as microbes have been selective agents of animals and plants, killing off the susceptibles, while the more resistant survived. They are operating in this selective way at present, though to a diminishing extent. Man, with his intelligence and will, interferes in a hundred ways in the natural processes which would dominate him if he were merely a brute. Obviously, he is justified in doing whatever seems to him essential for his betterment, and it is apparent that his interference with microbes has made his life increasingly safe from these invisible marauders and murderers.

It must not be lost sight of, however, that through the practice of many of the microbe-

preventing measures of modern public health and sanitation, man is rearing an increasing progeny of non-immunes, offspring lacking protection and adults who have had to fight fewer and fewer battles with the germs of disease. As long as man keeps up his preventive measures, his vaccinations and immunizations produced by mild artificial means; as long as man keeps his foods free from microbes of disease and his drinking water separate from his raw sewage; as long as man has either well enforced sanitary regulations or a keen public health conscience, he will be safe and physically prosperous behind these "cotton plugs" which keep microbes out of his system.

If he neglects them, as he might from a false sense of security, the "plug" will fall out, contaminating microbes will enter, and modern communities will have the most appalling epidemics in the whole sad history of the relationship of man and microbes. Unless great changes occur among the representatives of the primeval microbial inhabitants of this earth, man's safety among the microbes will be secured only by incessant vigilance.

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